FLEET TRACKING: A PROOF OF CONCEPT FOR IOT RELIABILITY SOLUTIONS

IMPROVING BROADBAND ACCESS IN RURAL VIRGINIA

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Computer Engineering

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October 31, 2019

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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The United States currently faces a digital divide in information accessibility, as rural communities have less access to broadband Internet services than urban communities (Prieger, 2013, p. 484-497). This disparity places rural regions at an economic disadvantage. A study by the United States Department of Agriculture (2009) found that increased broadband availability in rural counties improves employment rates and income growth (p. 21-22). Thus, without broadband access, rural communities can experience reduced economic development. The technical project and STS research will present two distinct methods that aim to narrow the digital divide and reduce this economic disadvantage.

The technical project will provide a proof of concept for techniques improving reliability in the Internet of Things (IoT), the network of connected devices (International Telecommunication Union, 2017, Volume 1, p. 99). The result will be a prototype for a fleet tracker system that uses two emerging technologies, solar energy harvesting and LoRa communications. The prototype will demonstrate that these two techniques can improve resilience in the IoT. In the context of the digital divide, the technical project will show that LoRa communications can transfer information without broadband service, enabling independence from broadband access.

The STS research will analyze the factors contributing to the limited broadband availability in rural Virginia from a sociotechnical perspective. The analysis will use Michel Callon and John Law's (1989) Actor-Network Theory framework, with a focus on the interactions between the global and local networks. The research aims to reveal that, in order to ensure the success of broadband initiatives, an established actor must moderate communications between the two networks.

While the technical project will take place over the course of a single semester, the STS research will occur over two semesters. As shown in Figure 1, the technical project involves five key tasks, addressing each of the major aspects of the project. The STS research is an iterative process, with steps from outlining the initial research topic to completing the research paper.

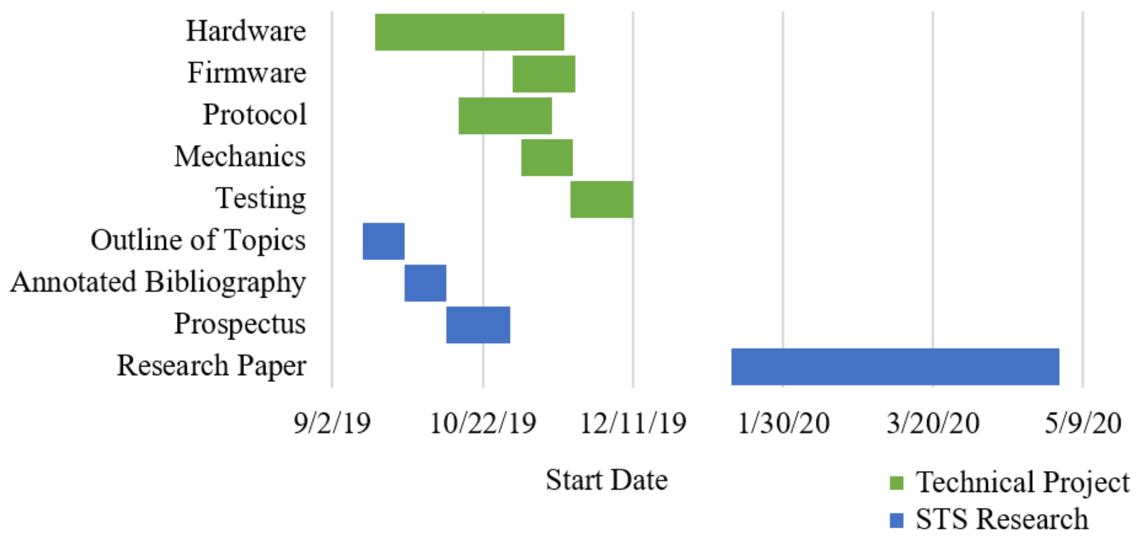

Figure 1: Gantt Chart for Technical Project and STS Research: The technical project will take place over one semester, from August 2019 to December 2019, while the STS research will occur over two semesters, from August 2019 to May 2020 (Lin, 2019d).

Together, the technical project and STS research present a technical and sociotechnical solution to the digital divide. There is loose coupling between these two projects. Although the research topic does not address the LoRa technology specifically, it answers why such a technique is necessary in rural environments. Additionally, an analysis of the factors contributing to low rural broadband access can help engineers ensure that new communications methods are reliable in all environments.

FLEET TRACKING: A PROOF OF CONCEPT FOR IOT RELIABILITY SOLUTIONS

The Internet of Things is a technological development that connects a widespread network of devices through wireless communications (International Telecommunication Union, 2017, Volume 1, p. 99). Due to the IoT's ability to enable constant information transfer, innovations that operate within it are relevant to a variety of stakeholders. According to a study by Bartje, applications of IoT devices include industry, agriculture, and health, among several others (as cited in Nord, Koohang, and Paliszkiewicz, 2019, p. 102). With this wide applicability, the Internet of Things plays a significant role in developing technological solutions to many problems (Nord et al., 2019, p. 102).

Current solutions relying on the Internet of Things, however, fail to accommodate certain environmental factors. One is the lack of a telecommunications infrastructure in rural areas. Gabe and Abel (2002) noted that on average, rural regions had half as many Integrated Services Digital Network (ISDN) lines per person as urban regions (p. 1250). Under these conditions, devices in the Internet of Things cannot ensure reliable information transfer. Another challenge has emerged with the increasing number of devices in the IoT (Kjellby et al., 2018, p. 1). The size of the network makes recharging and replacing all batteries inviable, resulting in offline times and data losses. Poor network infrastructure and intensive maintenance are both environmental factors that can reduce reliability in the Internet of Things, placing a restriction on the problems that the IoT can solve.

Two specific innovations have emerged to overcome these challenges. The first is LoRa, which is a method for modulating radio frequencies that increases the range of wireless communications (Semtech, 2015, p. 11). Existing literature has shown that LoRa modulation can provide reliable communication links even under variable environmental conditions and without an existing network infrastructure (Barro, Zennaro, and Pietrosemoli, 2019, p. 4; Rudes, Kosovic, Perkovic, and Cagalj, 2018, p. 3). The second innovation is the photovoltaic energy harvester, which powers devices through ambient solar energy. Prior research has demonstrated that solar power can support a device in the IoT (Kjellby et al., 2018, p. 4).

In order to prove that solar energy harvesting and LoRa communications can enable reliable operations under all conditions, the technical design project will use both techniques to implement a fleet tracker system. This system will track vehicles in real time through a reliable and secure network of wireless devices, called roaming nodes and home nodes. Figure 2 shows the network, as well as the key dataflow links within it. Although this figure shows several roaming nodes, the technical project will only use two. A network of this size will sufficiently demonstrate scalability, and it will be feasible to construct in the time frame of the project.

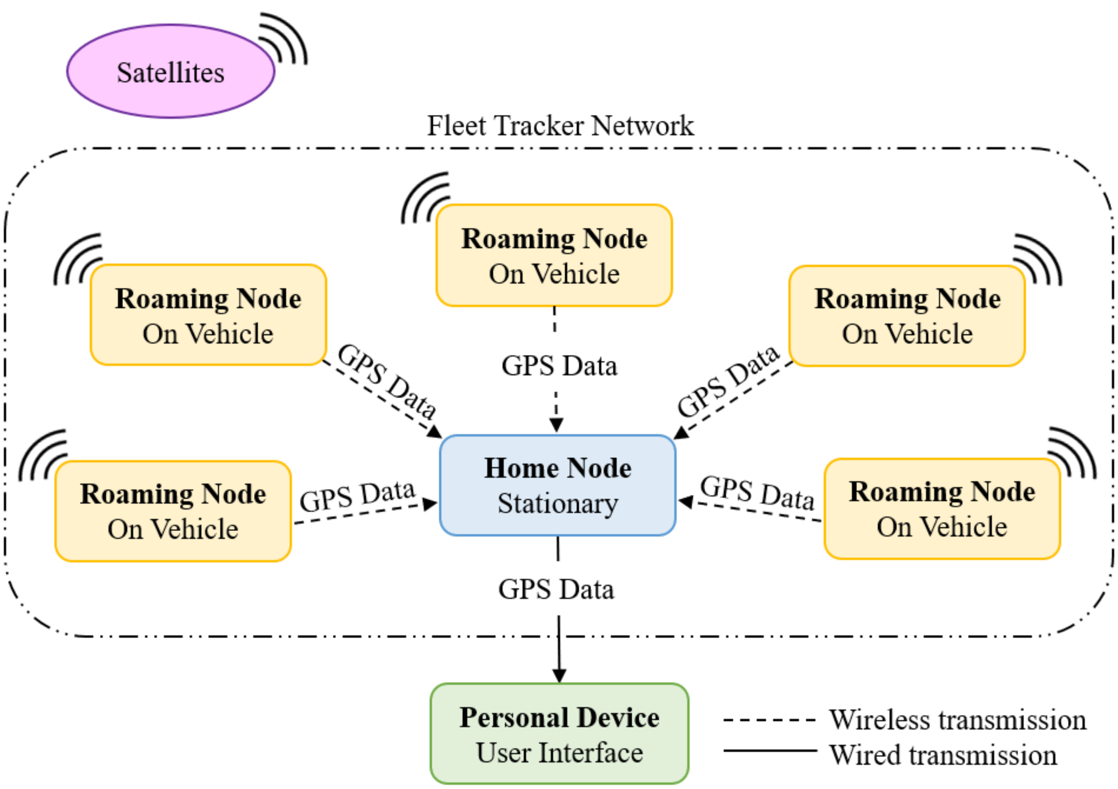

Figure 2: General Diagram of Fleet Tracker Network: Roaming nodes transmit GPS data to the home node, which relays the data to a personal device (Lin, 2019e).

As seen in Figure 2, roaming nodes, attached magnetically to moving vehicles, will send encrypted Global Positioning System (GPS) information to a stationary home node. The home node will then relay this data to a computer, which will display the vehicles' locations on a map. In order to eliminate the maintenance associated with single-use batteries, the roaming nodes will harvest solar energy. Additionally, the devices will communicate using the long range LoRa modulation technique, allowing for independence from a pre-existing network infrastructure.

The fleet tracker will require two distinct physical systems, the roaming node and the home node. The two hardware designs, as seen in Figure 3, must accommodate the roles of the two systems. Both the roaming and home nodes must include a power management unit, which will convert input power, whether from the sun or a personal device, to a form suitable for the electronic devices. Both nodes will also use a transceiver to wirelessly communicate with each other. In order to process data and control other components, the two devices will use the Texas Instruments MSP430F5529 microcontroller, a small-scale and low-power processing device (Texas Instruments, 2018, p. 2). Finally, only the roaming node will require a GPS receiver for GPS data acquisition.

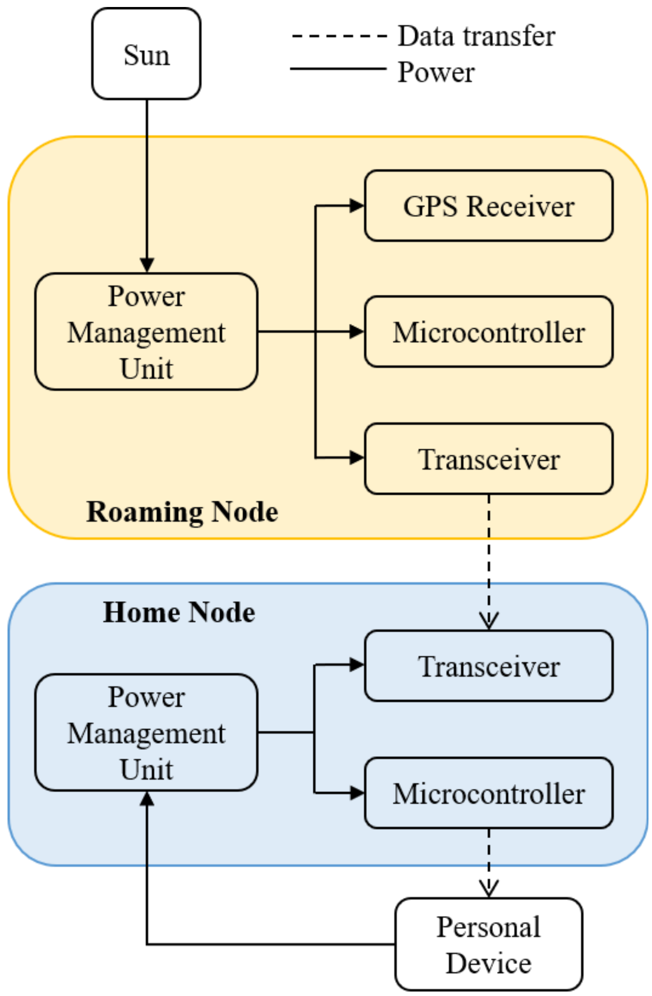

Figure 3: Block Diagram of Roaming Node and Home Node: The roaming nodes and home node each use a power management unit, a processing unit, and data transfer devices (Lin, 2019c).

Beyond hardware design, the use of solar energy harvesting and LoRa modulation introduces several challenges for the fleet tracker system. One key constraint is the limited power budget. The roaming nodes, operating on harvested solar energy, must sustain operations even when variable weather conditions limit power availability. The use of batteries, which act as an energy buffer, and non-continuous operations, which reduce power consumption, will ensure such reliability.

Another challenge is ensuring data fidelity. The fleet tracker will not rely on a pre-existing network infrastructure. Thus, the technical project will require original reliable data transfer protocols for node-to-node communications. A media access control protocol is also necessary to avoid the collisions that can occur when multiple devices transmit at once. Finally, in order to provide secure data transfer, the roaming nodes must encrypt the GPS data.

The design and construction of the fleet tracker will occur under the advising of Professor Harry Powell, from the Department of Electrical and Computer Engineering (ECE). Team members Vivian Lin, Jesse Dugan, Nayiri Krzysztofowicz, Malcolm Miller, and Nojan Sheybani, who are students in the ECE department, will complete the project in one semester. Departmental funding will support the purchase of electronic components and the manufacture of printed circuit boards (PCBs). The anticipated fleet tracker prototype will be a set of three PCBs, implementing two roaming nodes and one home node. It will demonstrate reliability in cloudy weather conditions and over long-range communications, proving through example that solar energy harvesting and LoRa modulation can improve reliability in the IoT. The team will present the results in a conference style paper along the guidelines of the Institute of Electrical and Electronics Engineers.

IMPROVING BROADBAND ACCESS IN RURAL VIRGINIA

Broadband Internet availability in rural regions is often much weaker than in urban areas, creating a digital divide in information access (Prieger, 2013, p. 484-497). In Virginia specifically, this divide is large. The Federal Communications Commission (FCC) defines fixed broadband as services with a minimum download speed of 25 Mbps and a minimum upload speed of 3 Mbps (U.S. Federal Communications Commission, 2018). According to these guidelines, 97.2% of urban Virginians have access to rural broadband, compared to only 71.1% of rural Virginians (Virginia Association of Counties, 2018a). This digital divide is evident in Figure 4, which shows the regions in Virginia that lack access to broadband Internet.

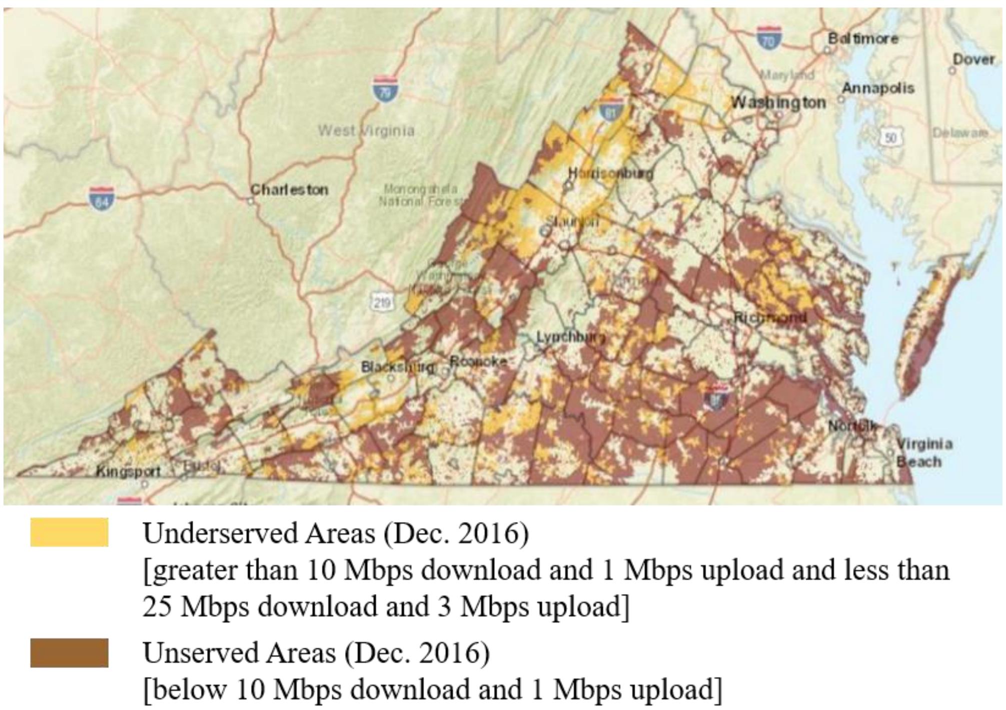

Figure 4: Broadband Coverage in Virginia: A large portion of Virginia communities lack broadband access (Adapted by Vivian Lin from Virginia Association of Counties, 2018b).

Such a disparity hinders economic progress in rural Virginia. The United States Department of Agriculture (2009) has found a positive correlation between broadband availability and economic success in rural regions (p. 21-22). For example, according to Virginia's Secretary of Commerce and Trade, the lack of broadband access has kept businesses out of Virginia's rural areas (as cited in Virginia Office of the Governor, 2019, para. 5). This trend places rural communities at a natural disadvantage compared to urban populations.

Understanding why rural broadband access is so limited can help to close this divide and reduce economic disparities. One way to perform this analysis is through Michel Callon and John Law's (1989) Actor-Network Theory (ANT) framework. According to Deborah Johnson, a professor of Applied Ethics at the University of Virginia, ANT "takes as its unit of analysis the systems of behavior and social practices that are intertwined with material objects... [It] emphasizes the presence of many actors, human and nonhuman" (Johnson, n.d.-a; Johnson, n.d.-b, p. 1792). Actor-Network Theory can consider both a global and a local network of such actors. The global network constructs the supporting conditions in which the local network implements a technology (Law and Callon, 1998, p. 289).

Prior research has used some element of ANT to analyze the factors contributing to limited rural broadband access. In 2016, Benjamin W. Cramer, a researcher at the College of Communications at Pennsylvania State University, considered the interaction between federal government policies, telecommunications service providers, and the American legal system (p. 996-997). Ali and Duemmel (2019), researchers at the University of Virginia Department of Media Studies, similarly analyzed the role of federal government regulators in supporting rural broadband access. They treated these regulators as a polycentric regulation regime, or a network of interdependent actors (pp. 381). The works of Cramer, Ali, and Duemmel, however, modeled rural broadband access as a single global network. Existing research that has also considered local networks, which affect the implementation of broadband infrastructure, also has flaws. For example, Durban Institute of Technology researchers Andrew and Petkov (2003) outlined key networks that can influence telecommunications infrastructure, including technical, local cultural, and political networks (p. 79-80, 82-84). Despite acknowledging the presence of a local cultural network, Andrew and Petkov failed to consider how the relationship between the local and global networks, in addition to the networks themselves, influence the spread of telecommunications technologies.

Existing research on rural broadband access does not provide a wholistic view of the rural broadband problem. Figure 5 illustrates this, showing an aggregate framework that combines the methods of prior analyses. As seen in Figure 5, existing literature treats the global network and local network as independent, ignoring the relationship between them.

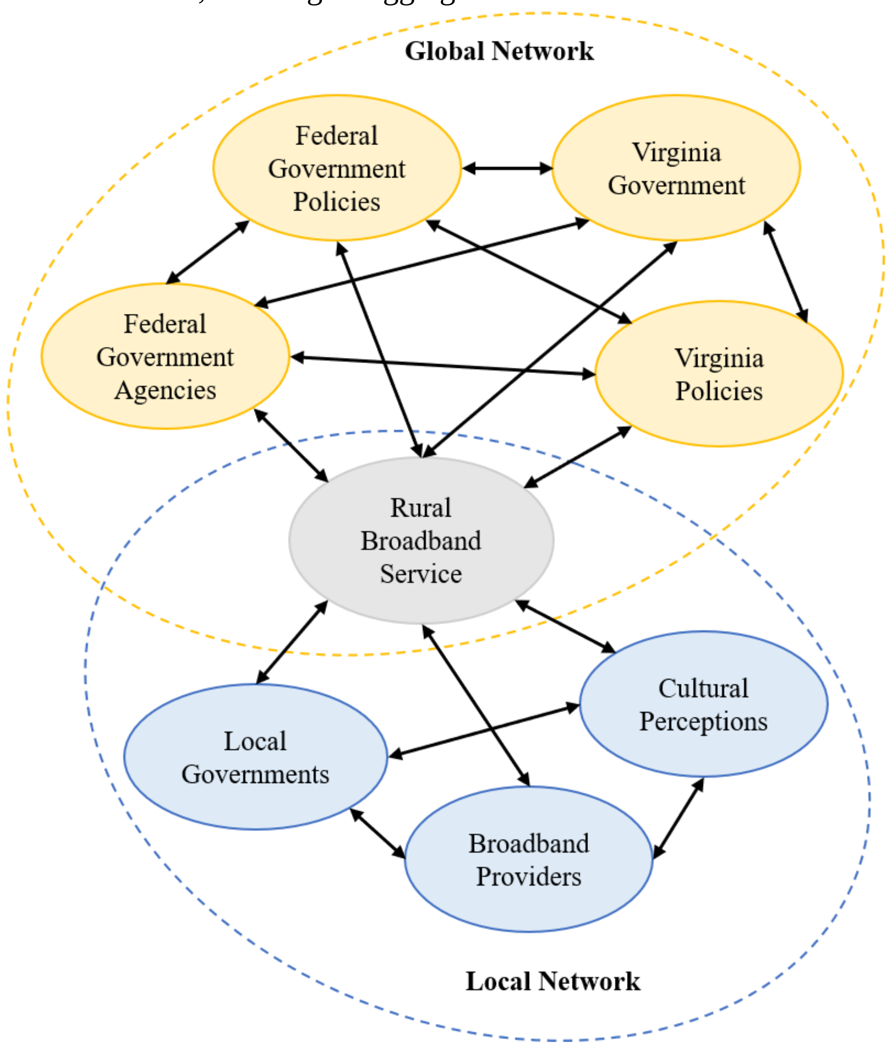

Figure 5: Actor-Network Theory Analyses in Prior Research: Existing literature treats the global and local networks as independent, without any interaction between the two (Lin, 2019a).

The STS research aims to fill this gap in existing methods. It will use Callon and Law's (1989) Actor-Network Theory framework, with an emphasis on inter-network relationships, to analyze rural Virginia broadband accessibility. Law and Callon (1998) stressed the importance of an "obligatory point of passage" in regulating the relationship between a local and a global network. An actor must establish itself as this obligatory point of passage, moderating inter-network communications, in order to preserve autonomy in what Law and Callon called the negotiation space (p. 290). The global network can create the negotiation space, or an "area of relative autonomy" from external influences, in which the construction of the local network will take place (p. 289). This autonomy, Law and Callon argued, is necessary to ensure that actors in the global network do not undermine the efforts of local actors to implement a technology (p. 292). Therefore, an obligatory point of passage is necessary to ensure the success of a technology.

The STS research will use ANT as a foundation for the analysis of rural Virginia broadband accessibility. It will first consider a global network and a local network. The research will then demonstrate that the lack of an obligatory point of passage has reduced autonomy in the negotiation space, creating conflicts in the global network that weaken rural broadband initiatives. Figure 6 summarizes the ANT analysis of the STS research.

As seen in Figure 6, the actors in the global network of rural Virginia broadband access include federal government agencies and federal policies. Ali and Duemmel (2019) introduced federal agencies, such as the Rural Utilities Service, as actors in the global network. These agencies provide financial support for actors in the local network to implement rural broadband services (p. 384). The Virginia state government and its policies are also global actors. The Utility Facilities Act (2016), outlined in the Code of Virginia, enacted roadblocks to municipal broadband service. A Virginia General Assembly bill similarly placed several restrictions on approval for municipal broadband facilities (Galaviz, 2017, para. 3). Thus, the Virginia state government and its policies support private broadband providers over public providers in the implementation of rural broadband services.

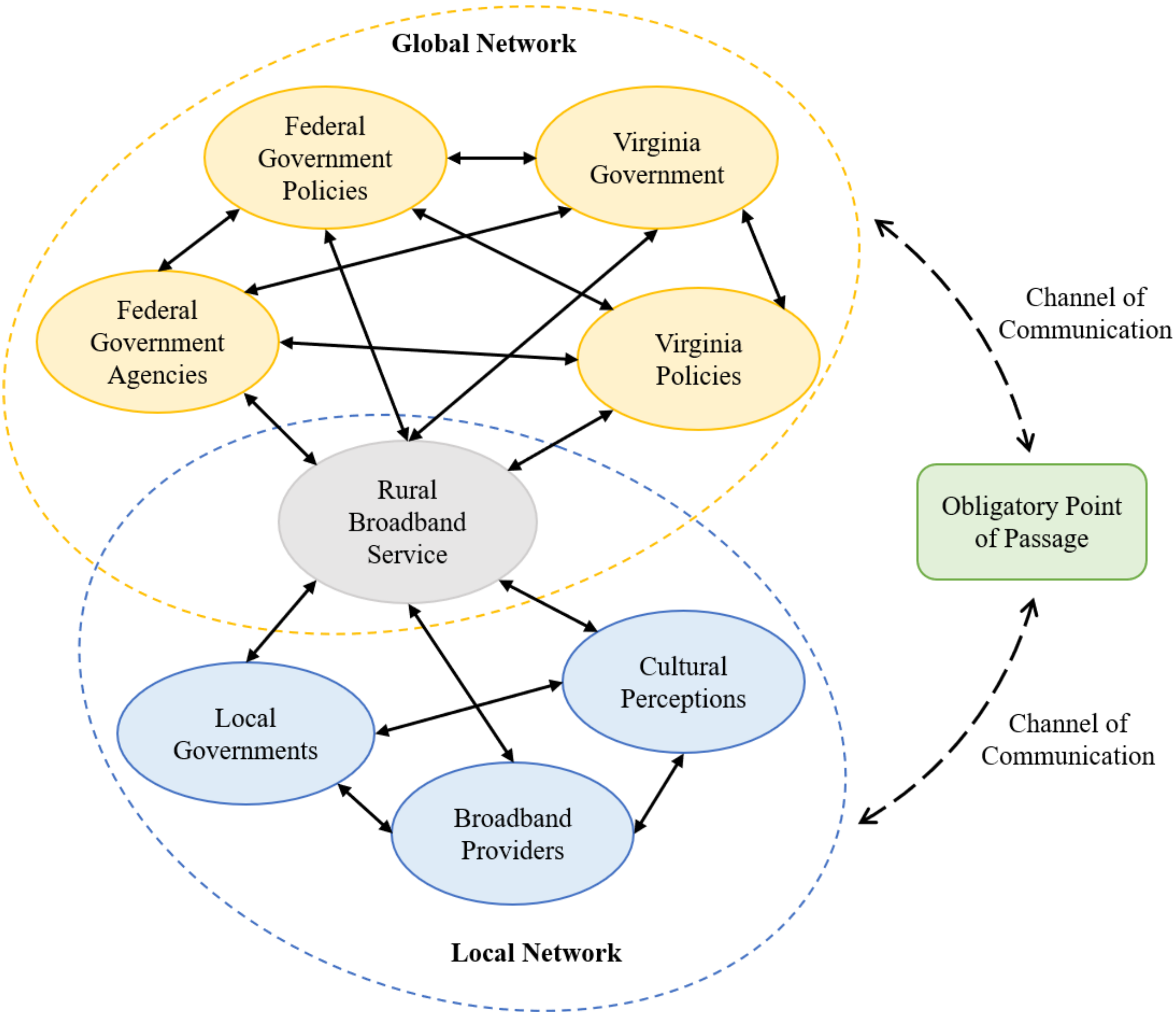

Figure 6: Actor-Network Theory Analysis in STS Research: The STS research will focus on how the global and local networks interact through the obligatory point of passage (Lin, 2019b).

Figure 6 also shows the actors in the local network of rural Virginia broadband access. These include broadband service providers, local governments, and cultural perceptions of local communities. According to Cramer (2016), outdated government regulations have allowed telecommunications providers to neglect universal service obligations, and ignore their legal responsibility to implement rural broadband services (p. 998, 1003-1004). This has pushed local governments in Virginia to establish their own municipal broadband services (Galaviz, 2017, para. 8; Martin, 2018, para. 4, 7). Finally, cultural views, such as the view of Albemarle County as a historic and scenic site, have caused opposition to physical rural broadband infrastructures (Albemarle County, 2000; Martin, 2018, para. 15-16).

Conflicts have arisen between actors in the global network, weakening the support system in which the local network implements rural broadband services. Ali and Duemmel (2019) noted that the undefined role of the Rural Utilities Service has led to a power battle between federal government agencies, creating unclear policies that weaken rural broadband initiatives (p. 391). Additionally, state governments and the Federal Communications Commission (FCC) have disagreed about the FCC's authority to interfere with state government broadband policies (Fisher, 2016, para. 1-3). According to Law and Callon (1998), these conflicts are due to the lack of an obligatory point of passage for communication between the local network and the global network (p. 292). Thus, the STS research will argue that rural Virginia broadband access is limited because no established obligatory point of passage exists between the two networks. Additionally, an established obligatory point of passage is necessary in efforts to expand rural broadband access in Virginia.

The STS research will occur under the guidance of Professor Catherine Baritaud, from the Department of Engineering and Society. Through an ANT analysis of the local network, global network, and inter-network relationship in rural Virginia broadband service, the research will provide a unique perspective of the rural broadband problem. Resulting in a scholarly research article, the STS project will seek to understand why widespread broadband services have failed to reach rural Virginia. It will also propose a solution to the rural broadband problem, aiming to close the digital divide in information access in Virginia.

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