The Design of a Simulation for the Modeling and Analysis of Public Transportation Systems as Opportunistic Networks

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Abstract

Vehicular ad-hoc networks, when combined with wireless sensor networks, are used in a variety of solutions for commercial, urban, and metropolitan areas, including emergency response, traffic, and environmental monitoring. In this work, we model buses in the Washington, DC Metropolitan Area Transit Authority (WMATA) as a network of vehicular nodes equipped with wireless sensors. A simulation tool was developed, to determine performance metrics such as end-to-end packet delivery delay.

Keywords: Opportunistic networks, Vehicular networks, Simulation, Network simulation

1. INTRODUCTION

Mobile ad hoc networks (MANET) have provided technological connectivity in areas where various constraints, including environmental, financial, cultural, time, and government prohibited the establishment of infrastructure-based networks. Nodes may be static or mobile, leading to a dynamic network topology. Routing of data occurs as nodes relay information to each other. Traditional ad hoc routing protocols assume the network is fully connected. In addition, the end-to-end source-destination path is assumed to be known prior to transmission.

The need for increased connectivity extends from urbanized areas to remote and rural areas previously unreachable via standard telecommunication networks. In either of these cases, the establishment or use of an infrastructure-based network is not always feasible, due to various constraints, including time, financial, cultural, government, and environmental. In addition, certain catastrophic events can render infrastructure networks useless.

Opportunistic or disruption tolerant networks (DTN) are special types of MANETs where no end-to-end path exists between source and destination nodes, due to a number of potential factors, including node mobility, physical obstructions, etc. Packet transmission occurs in a store-and-forward fashion, where nodes relay packets to neighboring nodes as they come in contact with each other, until the packet ultimately reaches its destination. As a result, packets must endure longer delays.

Vehicular ad-hoc networks (VANETs) are a special type MANET where cars or buses are equipped with devices that allow them to communicate with each other and any stationary equipment they may pass. These vehicles, referred to as nodes, are restricted to movement on streets or designated paths. In a major metropolitan area, public transportation systems can be utilized to provide opportunistic routing and delivery of data via buses. When equipped with wireless sensors, these networks can be used for a number of purposes, including health, environmental, habitat, and traffic monitoring, emergency response, and disaster relief [4, 10, 11, 15, 16, 20, 22].

In this work, we develop a simulation tool for modeling and analyzing a DTN comprised of buses in a public transportation system. Using real bus information and schedules, the simulation provides a realistic model of the entire network. This tool can be used to study various routing protocols and network performance metrics, such as end-to-end packet delay, packet copy distribution, and more. In addition, we provide a web-based front-end, using the Google Maps API, that provides a user-friendly interface for updating the network to account for a number of parameters and conditions, including inclement weather, traffic congestion, and other adverse conditions.

We note that, while this work uses the Washington Metropolitan Area Transit Authority (WMATA) system, the simulation can model any public transportation system that subscribes to the defined specification. It is the ultimate goal that this simulation will be used not only to study the use of the public transportation systems of cities for various societal and research purposes, but also to provide a means for any organization or individual to utilize this tool to gather relevant data.

The remainder of this work is organized as follows. In section 2, we discuss related work on DTN simulation models. In section 3, we present the network model. In section 4, we present the simulation model and web-based front end. In section 5, we present numerical results and a snapshot of our simulation application. In section 6, we conclude our findings.

2. RELATED WORK

Opportunistic or delay tolerant networks (DTN) have been suggested as a viable solution for a number of non-traditional mobile ad-hoc networks. These include providing connectivity in rural or remote areas, wildlife tracking and monitoring, and military battlefields, to name a few. A large majority of the work has focused on the development and analysis of routing protocols to measure a number of performance metrics, including end-to-end delay and packet copy distribution.

Recently, work in the area of DTN has shifted to include urban environments and the capabilities in these areas [2, 8, 10, 15, 19, 23]. Specifically, the use of vehicular nodes has been studied. These networks are assumed to perform a number of tasks, including traffic and environment monitoring, and emergency response, and disaster recovery. A large amount of work has focused on various routing strategies for these networks [1, 2, 3, 5, 7, 9, 11, 15, 16, 17, 18].

In these networks, there are a number of attempts to model various protocols using testbeds [12, 13, 14, 15, 23]. These testbeds range from small networks of robots emulating the movement of vehicles to actual buses equipped with processing capabilities. In each of these cases, there are limitations to the implementation. Mainly, the size of the actual networks can make the creation of an exact replica extremely difficult, if not impossible. Second, the implementation of these studies on the actual network can be difficult to implement, due to financial, regulatory, and time constraints.

Simulations are a viable solution to modeling and analyzing opportunistic networks exploiting vehicular nodes in urban areas [15, 16, 19]. These networks can be analyzed, in full, prior to implementation. The benefit in this research is the ability to study the performance of the network using a number of protocols and parameters. While these are easier to implement than physical testbeds, creating such a large-scale simulation, that incorporates a large number of nodes and data movement can quickly become complex. This requires adequate emulation of vehicular movement, data transmission, schedules, and more.

To the best of our knowledge, there is still much open research in the area of simulations of DTN in urban environments. Specifically, the use of public transportation (i.e. buses, subway, etc.) as vehicular nodes has only recently begun to receive attention. The complexity of such networks, due to the aforementioned schedules, number of nodes, etc. can make this type of network difficult to accurately simulate.

In addition, the aforementioned simulations are designed to address a specific network representation. Our simulation allows for various public transportation networks to be studied using the Google Transit Feed Specification. Simulation parameters do not require modification when studying various cities.

Our research focuses on developing a simulation tool that can be used to study DTN in urban environments exploiting the public bus system of any city. The novelty of our research is the development of a tool that can be used to study various protocols and metrics of interest by providing a common format for modeling any city, using a Google-developed specification for transit data. While simulations have been developed, to the best of our knowledge, our work is the first that incorporates real data, including schedules, sing Google Transit Feed Specification. The benefit of using this that the tool can be used to study any city whose public transportation information is provided via the specification. Furthermore, the web-based front-end provides a simplified mechanism for manipulating and executing the simulation.

3. NETWORK MODEL

The network is composed of all streets that comprise the WMATA public transportation grid, including Washington, DC-proper and adjacent cities in both Maryland and Virginia. A node in the network is represented by a bus. Each station and node is assumed to be equipped with processing capabilities and a small buffer. Each bus belongs to a bus (node) line, which has a pre-determined path comprised of a set of streets. We note that a single line contains multiple buses traveling in opposite directions, referred to as upstream and downstream. In addition, every bus on every line has an expected arrival/departure time to/from each designated stop along the line.

A stop is defined as a stationary bus stop or base station, where data collection/dissemination activities take place. We assume each stop is equipped with the necessary equipment (e.g. sensors, etc.) to collect and store data. At any stop, a packet is randomly generated that is destined for another stop. The packet is transmitted to the first node that reaches the stop after this generation. As the carrier node travels throughout the network, it transmits the packet to any node it encounters that is within transmission range. A packet is delivered once it reaches the destination stop.
In this work, we make the following assumptions:

- Packets are originated at and delivered to stops in the network. Buses (nodes) serve as intermediate carriers for relaying information from a source (stop) to destination (stop).
- A packet can be transmitted to a node or line that previously carried the packet.
- If two nodes are within communication range of the current carrier node, then the new carrier is randomly selected.
- At the end of the last bus route, buses store all packets in their respective buffers until the next day's routes begin.
- Packets arriving to nodes with full buffers are undeliverable. However, the transmitting node retains copies of the packets.

4. SIMULATION MODEL

To test our simulation, we used actual bus information from the Washington Metropolitan Area Transit Authority (WMATA). This information includes a total of approximately 1,400 buses on 350 different bus lines over approximately 80 sq. miles. We note that each bus line contains more than one bus in each direction.

In order to accurately and efficiently obtain and analyze real WMATA information, we used the General Transit Feed Specification (GTFS). GTFS is a Google-defined specification that provides a common format for mapping a city's public transportation with its associated geographic info using the Google Maps API [6, 21]. Using GTFS, the public transportation agency of any city can prepare a data feed according to specifications, validate it, and enroll in a partnership with the Google Transit team to launch the feed in GTFS. Submitted feed information includes subway, bus, and train info. The associated data is then displayed in Google Maps. Information provided via GTFS includes parameters such as station/stop name, longitude, latitude, bus/subway stops and lines, etc. A number of public transportation agencies across the country and globe currently have feeds in GTFS, including major metropolitan areas such as San Francisco, Boston, Philadelphia, Washington, DC, and New York.

Using a custom, Java-based discrete-event simulator, we model and simulate the movement of buses and data in the network. We use GTFS, JavaScript, XML, and the Google Maps API to build a custom, web-based front-end for our simulation. This front-end was developed to provide an alternative view of the simulation results. Users can not only view the resulting path that a delivered packet traverses, but also manipulate specific input parameters, such as number of network packets, start time, source-destination pairs, and adverse conditions (inclement weather, accidents, etc.) within a user-friendly environment. The front-end was developed with the goal of providing various agencies and authorities studying the use of public transportation for various research or application purposes could use the simulation, combined with the corresponding GTFS feed for a specific city, and easily manipulate the simulation, regardless of their level of knowledge regarding the simulation design and implementation.l

Using the information provided by GTFS and our discrete-event simulator, packets are randomly generated at stops, and transferred by nodes to destination stops. Each node has a small buffer that allows for the storing of packets in transit. The exchange of a data packet occurs when two nodes are within 500 ft. of each other.

5. NUMERICAL RESULTS

In this work, we simulate a seven-day time period in the WMATA. Packets are randomly generated throughout the network at various sources and at various times of day. In addition, we assume that packets are routed according to flooding. At the end of each day, all buses with packets in their respective buffers store these packets until the next morning's route begins. For our work, we use a maximum node buffer size of 12 packets and a maximum number of 10 unique packets destined for different source-destination packets in the network. We note that, while 10 unique packets are generated, there are multiple copies of these 10 packets present throughout the network.

Figure 1 presents a snapshot of the current web-based front-end. It should be noted that, in addition to being able to map the resulting path traversed, the simulation also allows users to input a number of parameters to manipulate the simulation, including weather conditions, rush hour starting time, packet size, etc.

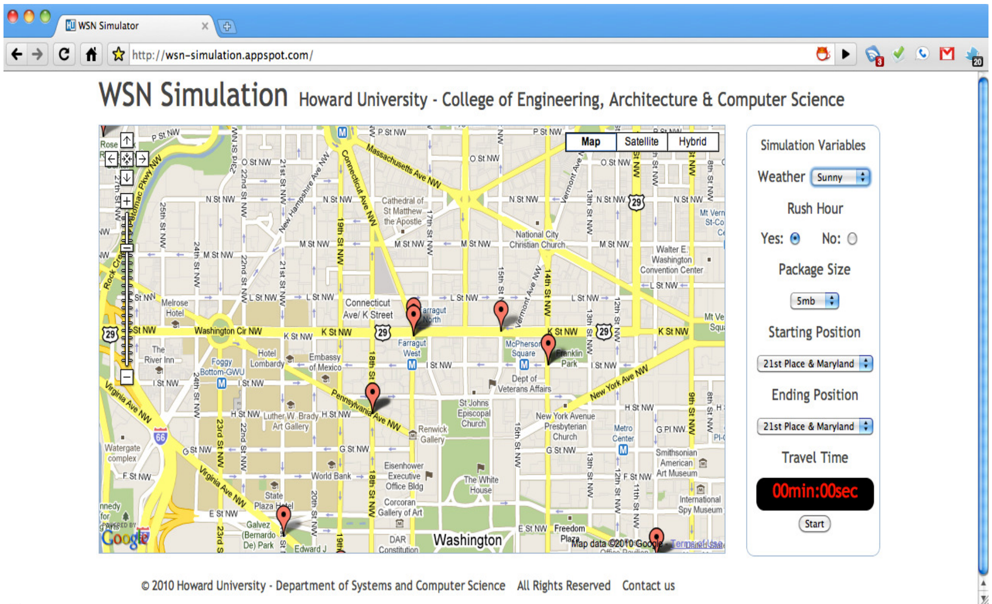

FIGURE 1: Web-Based Front End

Figure 2 presents the average end-to-end delivery delay of packets as a function of the size of the buffer. We note that, as expected, the delay is reduced when the buffer is introduced. In our previous preliminary work, we noted that a network with no store-and-forward capabilities (i.e. buffer size of 0) was significantly higher [19]. For this reason, we only focus on buffer capabilities in this work.

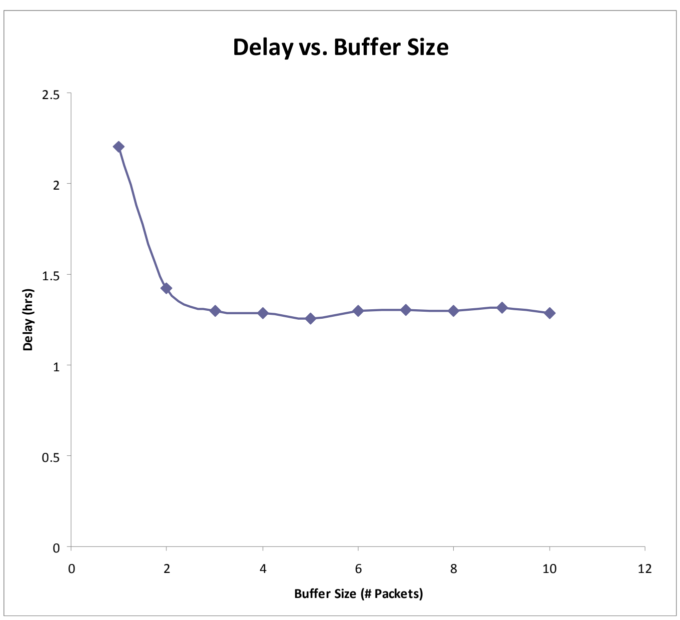

FIGURE 2: Packet Delay as a Function of Buffer Size

We also note that the delay varies slightly between 2 to 10 packets buffer size. We attribute this to a smaller number of network packets in the network. With increased number of unique packets and copies in the network, the delay variation is expected to be greater.

Figure 3 presents the average end-to-end delay as a function of the number of unique packets in the network. We note an interesting trend in this figure. As expected, as the number of packet copies increases, the end-to-end delay increases. We note the dramatic reduction in delay from 1 to 2 packets. This is due to the fact that multiple copies of an individual packet are now in the network, which allows for the probability of quicker delivery.

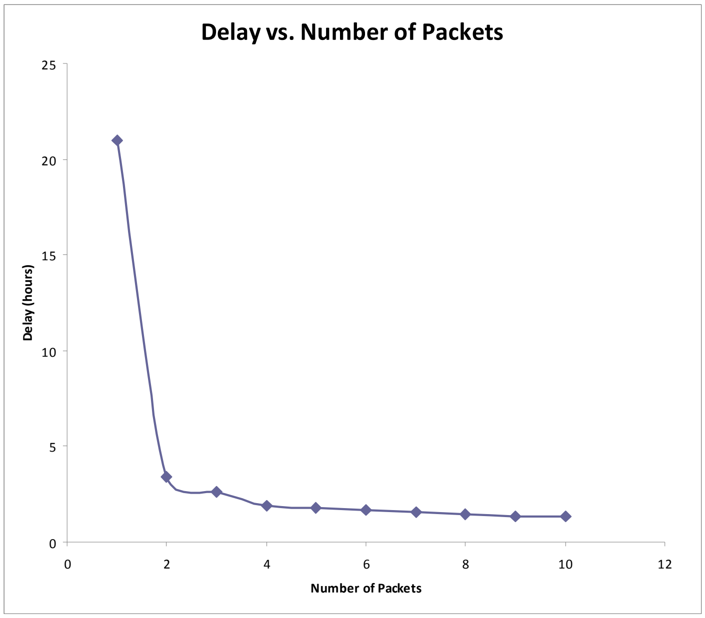

FIGURE 3: Packet Delay as a Function of Number Packets

6. CONCLUSION

In this work, we developed a discrete-event simulation to represent an opportunistic network comprised of vehicular nodes. A web-based front end was also developed via the Google Maps API, to allow a user-friendly method of manipulating network and simulation parameters. The simulation used real bus information from the Washington Metropolitan Area Transit Authority (WMATA). However, this simulation can easily analyze any system utilizing the General Transit Feed Specification (GTFS).

Currently, we are extending the capabilities of the simulation to include more unique source-destination pairs, complete parameter specification on the web-based front end, the incorporation of mobile base stations across the city, and the inclusion of additional node traffic (i.e. subway, people, cars, etc.).

We are also working on developing a model for approximating the analysis of the network. This work can ultimately be used to assist metro authorities in various cities with addressing optimization problems, such as costs, routing issues, and resource allocation. It can also be used to model the performance of various types of algorithms and protocols on such networks, including those used for emergency response, disaster relief, environmental monitoring, and more.

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