The Opportunistic Routing of the Washington Metropolitan Area Bus System as a Wireless Vehicular Node Simulated Network

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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. We developed a network simulation, based on the complete WMATA schedule, to model the network using opportunistic routing strategies. A web-based front-end was developed, using the Google Maps API, to provide a user-friendly display and control of the network map, input parameters, and simulated results. This application will provide users with a simplified method for modifying network parameters to account for a number of parameters and conditions, including simulation run period, starting time, and starting/ending positions.

Keywords: wireless sensor networks, vehicular networks, simulation, network simulation

1. Introduction

Vehicular ad-hoc networks (VANETs) are a special type of mobile ad-hoc network (MANET), where vehicles 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 typically restricted to movement on streets or designated paths. When combined with wireless sensor nodes, VANETS have been used for a number of purposes, including traffic and environmental monitoring, as well as providing network connectivity to vehicular passengers [1], [3], [4], [5], [6], [9].

In this work, we model and simulate a vehicular ad-hoc network model, based on the movement patterns of buses in the Washington Metropolitan Area Transit Authority (WMATA) network. A simulation model is developed using actual bus information and schedules that will be used to study the performance of this network, including end-to-end packet delivery delay, “hop” count minimization, simulation success rate 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. 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 present the network model. In section 3, we present the simulation model and web-based front end. In section 4, we present numerical results and a snapshot of our simulation application. In section 5, we conclude our findings and briefly discus future works concerning additions which will be made to further optimize the functionality of the simulators including: epidemic routing, packet flooding, event driven events and mobile packet send and receive capabilities from one vehicular node to another.

2. 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.

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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.

For this preliminary work, we make a number of simplifying assumptions:

- Packets are only forwarded in the network. They are not stored at any intermediate node.
- No node can carry a packet twice. Once it has previously received a packet, it cannot receive it again.
- A packet can be transmitted on a line that previously carried the packet.
- Packets remain in the network until they are delivered to the destination.
- If two nodes are within communication range of the current carrier, then the new carrier is randomly selected.

3. Simulation Model

In this work, the simulation uses information provided by the WMATA as the basis for creating and analyzing the vehicular ad-hoc network. 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 has more than one bus that travels the same pre-determined path.

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.

We note that GTFS provides arrival and departure times for every bus on every line in the city. Using this information, along with exact coordinate information (e.g. longitude and latitude), our simulation calculates the exact coordinates of any bus at any point in time during the day, allowing us to simulate the actual movement of buses throughout the entire city over the course of a simulated times period specified by the user. The exchange of a data packet occurs when two nodes are within 500 ft. of each other.

4. Numerical Results

In this preliminary work, we assume a single packet is generated at a random source, and is destined for a randomly-selected station. The packet is released at 2pm. The simulation runs until the packet is successfully delivered. We note that our simplifying assumptions result in a longer delivery delay, depending on the source/destination pair. However, it allows us to ensure the simulation model is correct. This simulation was run for multiple source-destination paths.

Figure 1 presents a snapshot of the web-based front-end for the simulation. 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.

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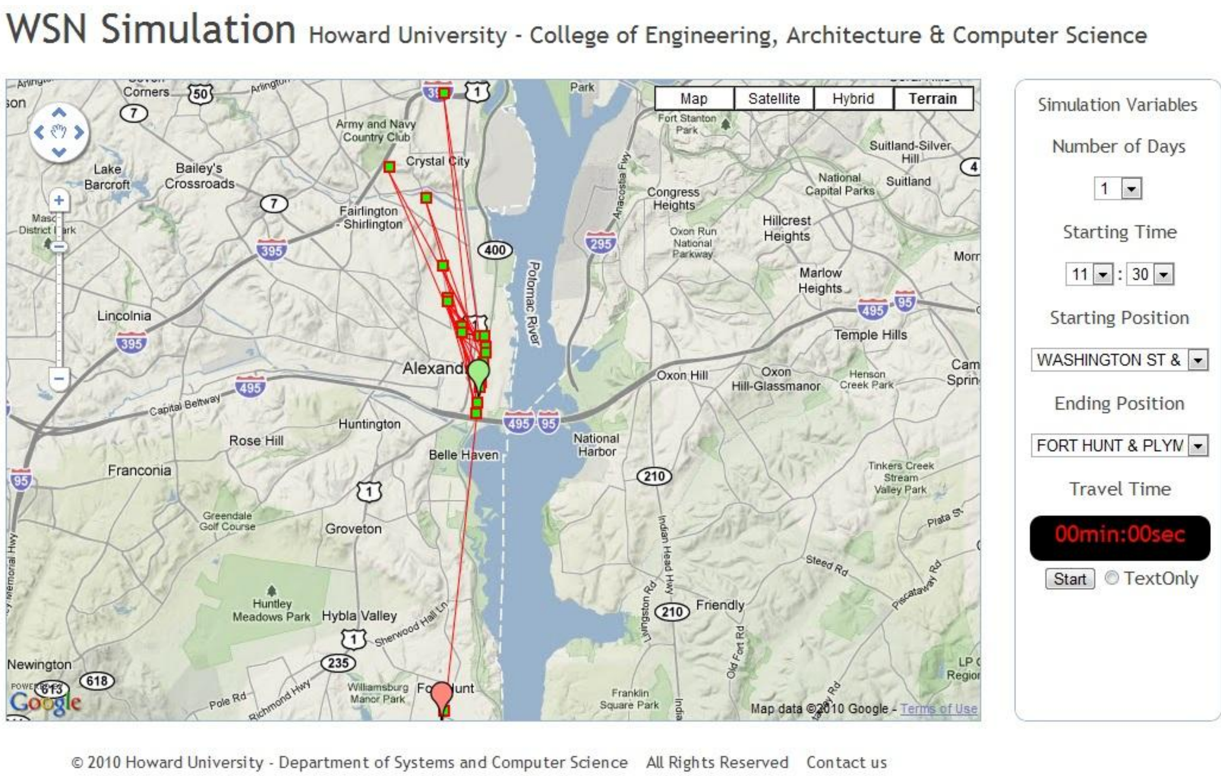

Figure 1. Web-Based Front End: GUI View

http://wsn-simulation.appspot.com

Figure 2 presents the end-to-end delivery delay of packets as a function of the number of network hops for one source-destination path created.

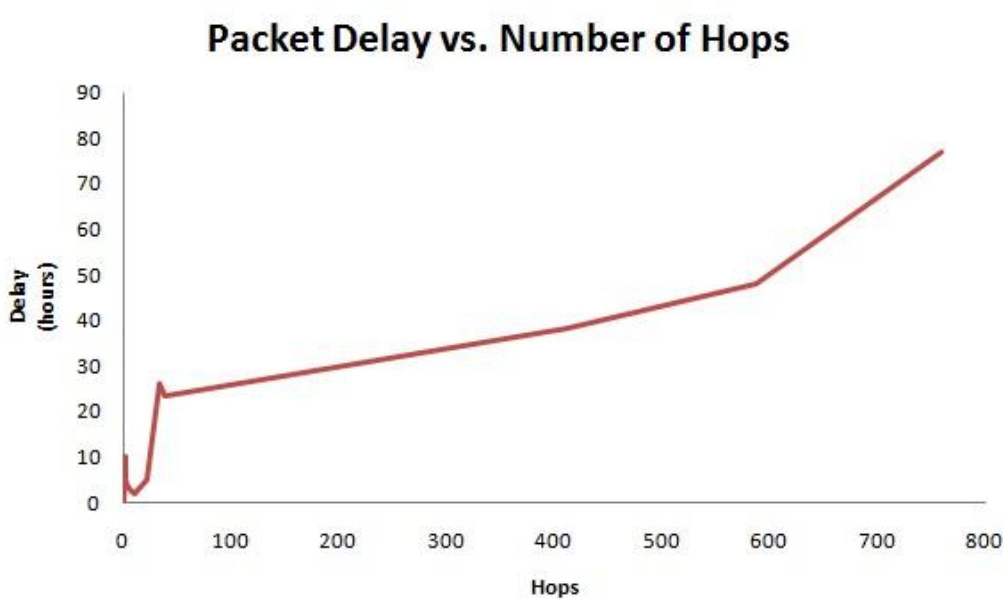

Figure 2. Packet Delivery Delay

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We define a hop as the number of intermediate nodes that carry the packet. Figure 2 shows that the delivery delay increases as the number of hops increases. We attribute this to the fact that the packet traversing more lines (i.e. pre-determined paths), understandably spends more time moving within the vehicular network. In order to decrease package delay, the simulation must decrease the amount of hops required. We also note that the end-to-end delay is large. We attribute this to the fact that packets are currently forwarded only. Allowing for store-and-forward capabilities will significantly reduce this delay because this will also significantly reduce the number of required hops. Introducing numerous copies of a data package into a network, flooding the network similar to an epidemic approach, may also greatly minimize the package delay within our simulated Wireless Sensor Network.

5. Conclusion

In this work, we developed a simulation model to represent a vehicular ad-hoc network. 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 results of this were designed and implemented using the WMATA bus system. However, this simulation can easily model any system utilizing GTFS.

Currently, we are working on extending the simulation to include more realistic assumptions, including store-and-forward capabilities, multiple packets inducing packet flooding to the network, and adverse conditions that affect the reliability of node arrivals and departures (i.e. rush hour, accidents, inclement weather, etc.). Currently the opportunistic routing simulation implements a time-base driven approach, however the next iteration of the simulation will be event driven approach allowing a dramatic speed improvement in the performance of the simulation. 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.

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