Experimental Characterization of Multi-hop Communications in Vehicular Ad Hoc Network

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ABSTRACT
This paper presents the performance measurement of TCP and UDP communication of a multi-hop Vehicular Ad Hoc Network (VANET) in highway and suburban areas. We use existing out-of-box IEEE 802.11b wireless cards on inter-vehicle communication between three cars. Also, we conduct experiments with three static nodes for baseline comparisons with the moving nodes. We then derive inferences in three major areas: (1) providing adjustable network parameters to manage network instabilities, (2) improving UDP efficiency by detecting out-of-touch receivers early, and (3) using speed, route, and distance to improve routing protocols.

Categories and Subject Descriptors
C.2.1 [**Computer-Communication Networks**]:
Network Architecture and Design – *Wireless communication.*

General Terms
Measurement, Performance, Experimentation.

Keywords
Multi-hop communications, VANET characterization.

1. INTRODUCTION
Vehicular Ad Hoc Network (VANET) is an ad hoc wireless network composed of moving vehicles such as cars and trains communicating with each other or roadside beacons. VANET has been envisioned as one of the most prominent technologies for improving the efficiency and safety of modern transportation systems [1]. This paper provides more insights on multi-hop inter-vehicle communication through actual experiments with common wireless equipments.

2. EXPERIMENT DETAILS
2.1 Experiment Set Up
Our experiment measures the following: (1) distance between the vehicles, (2) Round Trip Time, (3) signal strength, (4) TCP and UDP throughput, and (5) UDP jitter. We made the same measurements in two environments: highways and suburban areas. TCP and UDP throughput are also measured in an outdoor environment with three static nodes for baseline comparisons.

We set up three laptops running on Windows XP Professional Edition. We use the Windows default TCP window size of 64K bytes. The laptops are equipped with 802.11b compatible wireless cards and GPS receivers to collect location information for distance measurements. The route is statically configured to ensure multi-hop routing occurs on the roads. We use the Iperf tool [2] to collect TCP/UDP performance data, the Netstumbler [3] to measure signal strengths and the Ping utility for Round Trip Time measurements.

2.2 Driving Environment and Pattern
The data is collected in interstate highway 80 (I-80), I-5, and suburban areas in Sacramento, California. Our driving speed ranges from 5 to 70 miles per hour (8 to 113 kilometers per hour). The suburban area is usually filled with houses, 2-3 story buildings, trees, frequent traffic lights, and stop signs. The drivers drive the cars following each other.

3. RESULTS AND ANALYSIS
Our experiment results demonstrate the feasibility of multi-hop inter-vehicle communication in various driving speeds and conditions using common out-of-box equipments. Two-hop communication with three moving vehicles is achieved with distance of over 145 meters in between the sender and receiver.

We find that both signal quality and network performance varies greatly depending on the distance and availability of line of sight communication. Figure 1 shows the TCP throughput decreases as distance increases in both highway and suburban areas. The suburban scenario in our experiment contains more ups and downs because of the frequent stop signs and corner turns. For example, a dramatic drop occurs when both the receiver and the intermediate node lose line of sight with the sender at a sharp corner. Also, packet loss and jitter are much higher in vehicular communication than those in the static scenario as shown in Table 1. Table 2 shows the Round Trip Time measurements between 3 cars in our experiment. The measurements show that our highway scenario has the highest average delay for the distance range 5-145 meters. The delay in highway is caused by the higher median distance between the nodes and the entrance and exit of highway on curve ramps.

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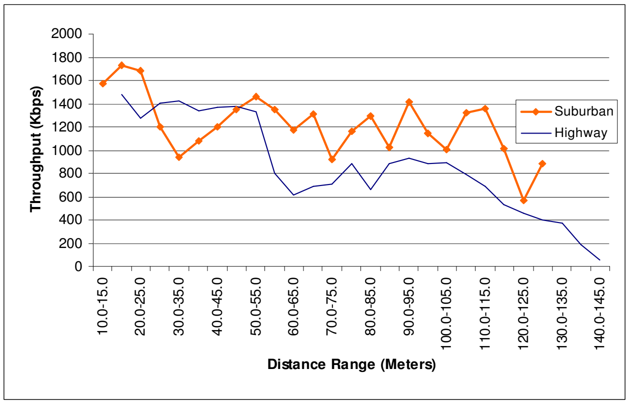

Figure 1. TCP Throughputs vs. Distance

Table 1. Statistics summary of UDP Throughput, Jitter, and Datagram Loss in 3 scenarios

	Environment	**Median**
UDP Throughput (Kbps)	Highway	497 Kbps
	Suburban	759 Kbps
	Static	2352 Kbps
Jitter (ms)	Highway	20 ms
	Suburban	30 ms
	Static	5 ms
Datagram Loss (%)	Highway	3%
	Suburban	4.3%
	Static	0%

Table 2. Average and median Round Trip Time (RTT)

	Average RTT (ms)	**Median RTT (ms)**	**Average Distance (Meters)**
Highway	7.4	5.9	86.7
Suburban	6.5	5.5	65.8
Three static nodes	4.8	4.5	N/A

4. INFERENCES

4.1 Managing Network Instability

Our experiment shows that network performance and signal strength can vary dramatically depending on the distance, interferences, and line of sight communication. Also, network connections may drop in and out frequently. Applications that assume stable, always-on connections can have a lot of problems in VANET environments. For example, the Iperf UDP server crashes frequently when it loses its connectivity to the client in the middle of receiving a UDP stream. A robust VANET application needs to adapt to different network performances. For examples, enduring network lose-end connections, scaling TCP window size option [4], adjustable timeout values, and sending rates can potentially improve the robustness and performance of VANET applications.

4.2 UDP Efficiency in VANET

In this experiment, we find that TCP is more efficient than UDP in general. This is because the receiver drops in and out of communication range frequently but UDP senders continues to send data to the intermediate nodes regardless whether the receiver is still receiving or not. As a result, UDP senders can waste the bandwidth of intermediate nodes for a period of time. On the other hand, TCP sender sends a chuck of data and wait for the receiver's response before sending further data to the intermediate nodes. As a result, TCP sender can detect a disconnected receiver and stop transmitting data to the intermediate nodes sooner than UDP senders. Our observation suggests there is a need for smart algorithms to inform the sender early about the receiver's failed connection status. These algorithms can prevent the sender from burdening the intermediate nodes by transmitting large files or streaming video to an out-of-touch receiver.

4.3 Using Speed, Route, Distance, and Position to Improve Routing Protocols

We believe that routing protocols can use speed, route, distance, and position to improve routing performance. Distance and line of sight communication are the two main factors affecting the network communication in our experiment. Distance is directly affected by the relative velocity and the position of the nodes. Line of sight communication depends on the route that can be obtained from digital maps. For example, we are often out of line of sight in residential areas that have many corners. If the nodes can exchange information about their speed, route, distance, and position with each other, they can make more intelligent routing decisions. For example, the speed and route can be used to predict the position of a node in position-based routing instead of having the node to update its location frequently. Authors in [5], for example, have used the distance and velocity of two nodes to predict the connection lifetime of a path. Also, we believe that route and distance information can be used in topological routing to select the best route to use.

5. REFERENCES

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