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Impact of Transmission Power on the Performance of UDP in Vehicular Ad Hoc Networks

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***Abstract*—With the availability of cheap and robust wireless devices there is demand for new applications in Vehicular Ad-hoc Networks (VANET). The challenge in implementing applications is in understanding of the complex dynamics of highly mobile multi-hop ad hoc networks which is a characteristics of VANET. Studies have been reported that attempt to quantify transport protocol (TCP and UDP) performance in mobile ad-hoc network in general and VANet in particular. However, very little work has been done in looking at the effect of tuning transmission power and its effect on the performance of the transport layer protocols. Our work specifically looks at the result of tuning transmission power and its effect on UDP throughput in VANet. To facilitate this study we first developed a comprehensive integrated simulation tool which accurately simulates both vehicular mobility patterns and wireless network environment and the communication protocols; the former is based on a cellular automata model while the later is developed using JIST/SWANS network simulator. Results show that the major mitigating factor in VANETs multi-hop environment is the number of hops between the source and the destination. Increasing the transmission range results in decreasing the number of hops between source and destination effectively increasing throughput. However, increasing the transmission range beyond a certain point saturates the throughput due to increased interference. We also found that the effect of vehicle densities is only important at lower transmission ranges to provide the required connectivity.**

I. Introduction

The specific focus of this work is applications of vehicular ad hoc networks, which are enabled by the deployment of wireless networking devices in vehicles. Using wireless communication capabilities, vehicles can communicate with each other, roadside access points, traffic sensors, and other devices that are within transmission range. As more and more vehicles are increasingly equipped with processing and storage capabilities, the opportunity and foundation to leverage these communication channels to perform a variety of tasks also increases. This may include local-scale applications, such as traffic management and monitoring, to Internet applications, such as streaming multimedia and VoIP.

Applications developed for such vehicular ad-hoc networks must take into consideration the underlying attributes of VANET, which include dynamically-changing topologies due to vehicle movement, channel interference from other users and from the environment. Unlike other MANETs (Mobile Ad-hoc Networks) VANETs follow well-studied mobility patterns, constrained by roads and human behavior. In this paper, we focus on the performance of the User Datagram Protocol (UDP) in such an environment. Specifically seek to understand the effect of tuning transmission power and its effect on the performance of UDP in VANET.

There have been several recent studies analyzing UDP performance in VANET. [1] quantifies UDP performance in VANETs measuring both UDP throughput and UDP jitter. Their study shows that behavior and throughput fluctuates greatly with respect to distance and line of sight. They also show that packet loss and jitter are much higher in the mobile vehicular scenario than static scenarios. In [2], an analytical study of tuning transmission power in VANET, the authors show how to optimize channel utilization using traffic density. Other studies such as [3] and projects such as FleetNet [4] [5] focus on the performance of vehicular networks with particular focus on the routing protocols.

All of these recent studies either characterize the performance of TCP/UDP or look at the effects of transmission power. Others look at aspects outside of transport layer protocols and power tuning. The uniqueness of this study is the extensive simulation tool with realistic vehicular mobility patterns developed to closely model the VANET environment and the focus on the relationship between power management and UDP performance. To date, no extensive study has been performed on understanding UDP behavior and varying transmission power in vehicular systems under a realistic mobility model.

The key contributions of this work are the following. First, we develop an integrated simulation tool that accurately models both the vehicular traffic flow as well as the wireless networking and UDP protocol. This has been achieved by integrating a Cellular Automata based vehicular micro-simulation model with a discrete event wireless and networking protocol simulation tool based on SWANS (Scalable Wireless Ad Hoc Network Simulator) and JIST (Java in Simulation Time) [6]. Our study finds that throughput is primarily influenced by the number of hops between the source and the destination. Since transmission range is correlated to the average number of hops we find that increasing transmission range results in higher throughput. We also find that at a certain point increasing transmission range no longer is beneficial since the incease in throughput flattens due to higher interference.

The remainder of this paper is organized as follows: Section 2 is the problem statement. Section 3 illustrates the simulation tool used in this study. Section 4 describes the simulation

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setup. Section 5 contains the results and analysis and section 6 concludes the paper.

II. Problem Statement

With the widespread emergence of robust wireless technologies and the high demand for wireless applications, significant research has been done in VANET. Vehicles equipped with GPS and 802.11 wireless network cards can form a vehicular ad-hoc network that forms a distributed networking and computing platform. We refer to such vehicular-based ad hoc computing grid as VGrid [7]. The VGrid framework is a platform in which vehicles combine on-board computing, networking and memory resources in order to solve networking and traffic problems in a distributed fashion.

The VGrid framework can be used to provide crucial and life saving applications such as accident alert systems and collision warning systems designed to alert drivers during dangerous driving scenarios. However, VGrid can also be used to provide "infotainment" applications, such as global Internet access or on-demand, peer-to-peer applications. For example, CarTorrent [8] allows vehicle to exchange, through single hop or multi-hop communication, movies and audio files. Vehicles could also form a grid network to facilitate multihop connections to access points along the highway.

The VANET environment is very dynamic and interactive, which results in unpredictable TCP performance, especially in these multi-hop wireless networks. TCP performance over multi-hop wireless networks can be very poor due to the underlying congestion control protocols such as slow start. In addition, many infotainment applications such as audio and video streaming use the UDP transport protocol. As a result, we choose to focus on the performance of UDP in VANETs. In order to provide reliable communication, it may be better to implement a reliable protocol over UDP than to rely on TCP. By better understanding the benefits and drawbacks of tunning transmission power and its relationship with UDP performance, we can also better understand what effects tuning transmission power will have in a TCP environment. In some cases UDP has been shown to have performance benefits in scenarios with high delay such as cross-country or cross-continental routes. UDP variants such as Reliable Blast UDP (RB-UDP) [9] have been shown to out-perform the standard TCP protocol in such systems. In the process of understanding UDP, our goal is also to pave the way for future work in developing better transport protocols, whether variations of existing protocols or new ones, for VANETs.

III. Simulation Tool

The VGrid simulation tool is based on SWANS, a Java based network simulator. The SWANS network simulator uses JiST (Java in Simulation Time), which is an event driven simulation tool [6]. The JiST simulation platform is very efficient; it out-performs existing highly-optimized simulation tools both in time and memory usage. With the VGrid simulation tool, vehicular movements and applications are transformed into events that are processed by the JiST event driven platform.

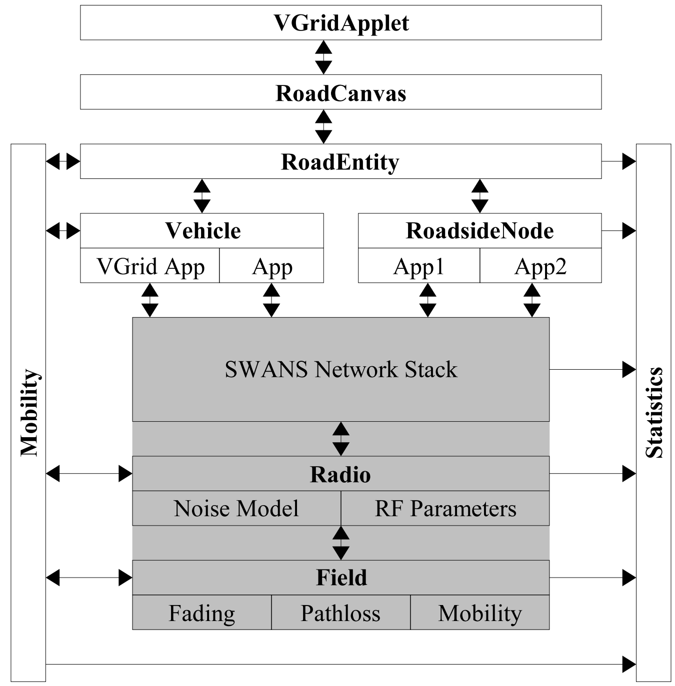

Fig. 1. Overall design of the VGrid Simulation Tool. Existing SWANS components shaded in gray. All components run on top of the JiST event-driven platform.

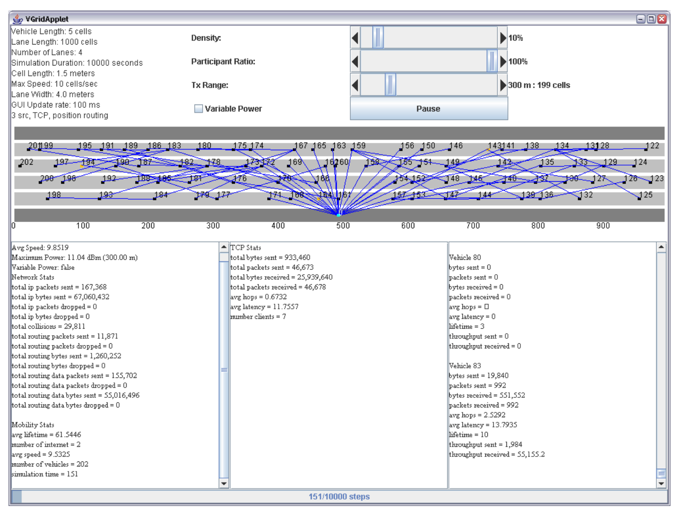

Fig. 2. Screen capture of simulation tool.

The network simulator and the vehicular traffic model run on a feedback loop.

Information obtained from the SWANS network simulator is processed by each vehicles mobility applications then fed into the mobility model. The mobility model then updates vehicle positions and based on these updated position antenna positions are updated for the SWANS network simulator. The high-level design is illustrated in Fig. 1. In addition, the SWANS network simulator and vehicular mobility simulator both update a graphical interface that allows network and vehicular mobility parameters to be changed dynamically, as shown in Fig. 2. The strength of this simulation tool is the integration of a comprehensive network simulator with an accurate vehicular mobility simulator.

The vehicular mobility model is based on cellular automata, specifically the Nagel and Schreckenberg (N-S) model [10]. In this model, the road is divided into equal-length cells of size Δx=7.5m with each cell containing 1 vehicle. The simulation time granularity is Δt=1s, i.e., new vehicle positions are calculated using the N-S model every second. For the purpose of this study, we have extended the basic N-S model to more accurately reflect real-world traffic based on the work in [11] and by adding lane-changing capability.

The SWANS network simulator provides a variety of components that enables an accurate network simulation. At the application layer, SWANS provides the standard application network interfaces. It also includes both UDP and TCP protocols at the transport layer. In this paper, we focus on the UDP performance. We also implement a simple position based routing protocol, which leverages the GPS devices that are already present in the vehicles. SWANS also includes standard 802.11 MAC layer protocol and several path loss models and fading models at the physical layer.

IV. Experiment Setup

We simulate a 4-lane highway for our experiments. The highway is broken up into 1000 cells, where each cell is of size 1.5 meters. Lane width is 4 meters. Simulations last until 20 active vehicle enter and exit the road. Vehicle speeds range from 0-20 meters/second. Each vehicle has a length of 5 cells (7.5m) and a percentage of vehicles (the participation percentage) are equipped with 802.11 wireless device and GPS devices. We place one access point at the mid-point of the highway (in this case location 500) on the side of the road. The number of vehicles on the road is fixed at all times. Vehicles that exit the road ”wrap around” and re-entire the road at the same speed. Initially 10 active vehicles are randomly placed in the simulation highway.

The goal of this study was to quantify the effect transmission power on UDP throughput. The key parameters include:

- Traffic Density: Percentage of cells occupied by vehicles. At 100% density 800 vehicles are present.
- Participation Percentage: Of the vehicles entering the highway, a fraction of them are equipped with a wireless IEEE 802.11 device and a GPS device, i.e., VGrid enabled. We refer to this fraction as the participation percentage, denoted by P. We will refer to these vehicles as participating vehicles.
- Active Vehicles: In order to monitor UDP performance, some vehicles run a UDP application that generates packets at a constant bit-rate to be sent to the access point. Active vehicles will be considered participating since they must also be equipped with both a wireless IEEE 802.11 devices and a GPS device.
- Transmission Range: Actual transmission range relies on a number of factors, such as SNR and receiver sensitivity, but for simplicity, we define ”transmission range” as how far a signal would travel given perfect channel conditions (no background traffic, no interference, etc).
- Routing Protocol: In this study, we use a simple positioning-based routing protocol described in [12].

TABLE I
SIMULATION PARAMETERS

Traffic Density	10%, 30%, and 50%
Participation Percentages	25%, 75%, 50% and 100%
Active vehicles	10 Vehicles
Transmission Ranges	100 m, 200 m, 300 m
Routing Protocol	Position Based

The values for these parameters used in our experiments are listed in Table I.

The position-based routing is based on the greedy forwarding concept from GPSR [12], in which packets are forwarded through nodes geographically closer to the destination than previous node. That is, the position of the next hop will always be closer to the destination node than that of the current hop. We do not consider the ”perimeter routing” mode of GPSR that searches for alternate routes that may not be geographically closer, since in a highway scenario, the width of the road is generally smaller than the transmission range. In this scenario, there is no way for a route to move away from the destination and still find its way back. Therefore, if a node cannot find a route to the destination, it will simply queue the message and check every $RETRANSMIT\_DELAY$ seconds to see if a route has been found. If this fails $MESSAGE\_TTL$ times, the message is dropped.

The operation of position-based routing depends on the timely dissemination of location information by each nodes in the network. This is accomplished through periodic beacons. Every $BEACON\_INTERVAL$ seconds, every vehicle will broadcast its own location to its neighbors. Using this information, all vehicles in range will be able to build a map of one-hop neighbors. Since vehicles can leave the road, nodes are removed from this map if no update has been received in more than $INFO\_TIMEOUT$ seconds. The values for these parameters used in our experiments are described in Table II.

In our simulation, we assume that the location of the access point is known a priori. When a vehicle wishes to send to the access point, it will first broadcast its location information, alerting the next hop vehicle of its current position even if it is between beaconing intervals. Each subsequent hop will do the same thing, broadcasting the location of the original sender so that the access point and all vehicles along the path will know the location of the sender even if it is many hops away. This allows for position-based routing to work in the reverse direction without requiring every node to have a complete map of the entire road.

In the simulations, we look at two different bitrate scenarios. In the low bitrate scenario, each vehicle transmits at a bit rate of 1.2 Kbps or 12 Kbps. This, of course, greatly underutilizes the channel. Secondly, we chose a high bitrate scenario where 10 vehicles running a constant bit rate application of 100 kbytes/sec. Total data being sent is 10*100 kbytes/sec or 1

TABLE II
ROUTING PROTOCOL PARAMETERS

BEACON_INTERVAL	Delay between position beacons	1 sec
RETRANSMIT_DELAY	Delay between forwarding attempts for a packet	1 sec
MESSAGE_TTL	Number of times a node will attempt to forward a packet	5
INFO_TIMEOUT	Lifetime of a position beacon message	5 sec

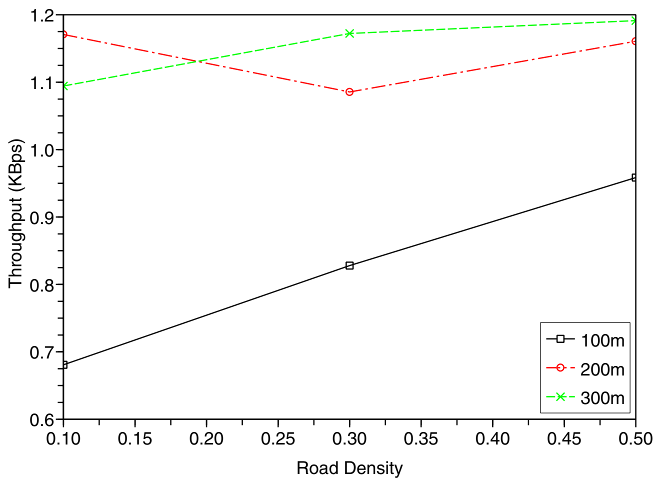

Fig. 3. Throughput as a function of vehicle density at transmission ranges of 100, 200, and 300 meters. There is one active vehicle sending at 1.2KBps and participation rate is 100%.

Mbs (8 Mbits/s) which is 70% utilization of the channel of 802.11b, which has a raw capacity of 11 Mbps. Unlike the previous low bitrate experiments we wanted to observe throughput fluctuations in a saturated system.

V. Results

In this section, we present the results of our simulation study. We present the results in two parts: 1)In order to begin to understand UDP behavior over a wireless ad hoc vehicular network we first look at UDP performance at low load, i.e., low bit-rate scenarios, and 2) We look at high load, i.e., high bit-rate scenarios.

A. Low Load Scenario

With a low bitrate the majority of performance loss should be due to the loss of connectivity. Figure 3 shows for both 200 and 300 meter transmission ranges the throughput is nearly at maximum. The slight under utilization can be attributed to occasional packet loss due to collisions and path loss. For 100 meter transmission range we see a linear increase in throughput with traffic density due to the increase in connectivity, which is the result of the increase in traffic density.

At high transmission range and higher densities, there is sufficient connectivity to ensure that nearly every packet arrives at the destination. At low density and low transmission range, connections break due to a lack of vehicles in range. Finally, for any fixed pair of parameters in (transmission range, participation rate, density), we can find a critical point after which connectivity is guaranteed.

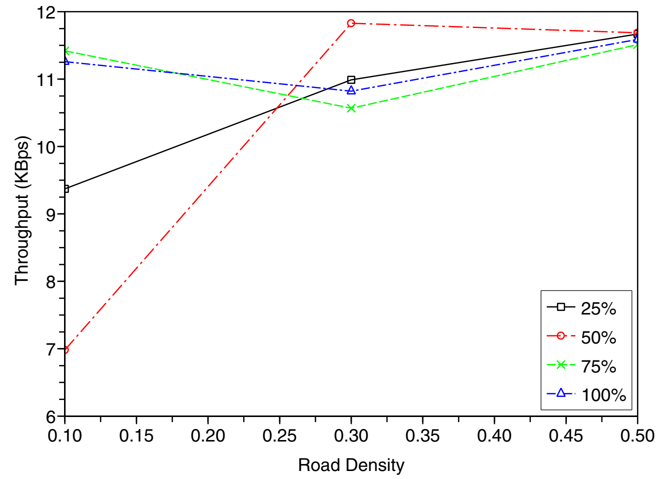

Fig. 4. Throughput as a function of density at varying participation rates. There is one active vehicle sending at 12KBps and range is fixed at 200m.

We can again see this critical connectivity point in the results from the 12Kbps scenarios. As in the 1.2 Kbps scenario, 12Kbps still greatly under-utilizes the channel. As a result we expect much the same results in the 12Kbps scenario as 1.2 Kbps scenario with the exception that we might see a slight performance degradation due to a higher collision rate. Fig. 4 and Fig. 5 both illustrate the critical connectivity point and the utilization of the channel. Figure 4 results show that at higher participation rates (75% and 100%), connectivity is stable and thus the throughput is maximized. At the lower participation rates (50% and 25%) and low density (.1) the number of participating vehicles has not reached a point where connectivity is stable. This is the reason for the observed loss in throughput. However as density increases to 30% the number of participating vehicles increased sufficiently to stabilize connectivity at which point throughput also increases to the higher point. This critical point is also visible in Fig. 5; however, in this situation the higher transmission range of 300 meters results in stable connectivity with less required participating vehicles. Fig. 5 shows that for all participation rates and densities this stability point is reached except for 25% penetration at the lowest traffic density of 10%.

B. High Load Scenario

In all the high bitrate experiments there was one conclusion that was consistent among all variations of density and penetration. We observe that an increase in transmission range was correlated to an increase in throughput. This can be explained by observing the effect of increasing transmission range in vehicular multi-hop networks. We find that increasing transmission range has the anticipated effect of also increasing loss due to interference. We also find that, as expected,

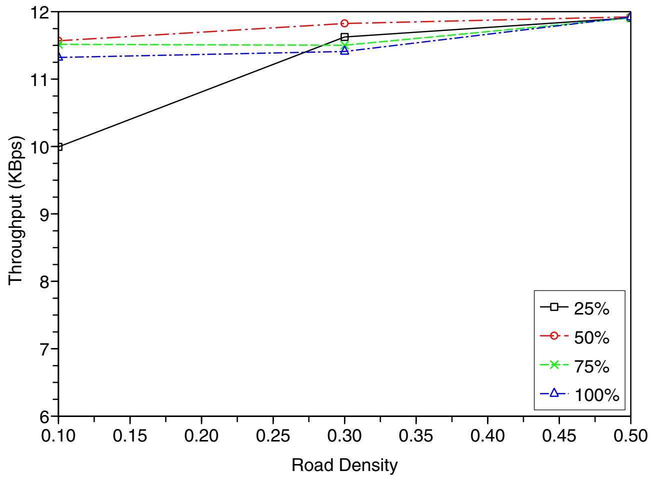

Fig. 5. Throughput as a function of density at varying participation rates. There is one active vehicle sending at 12KBps and range is fixed at 300m.

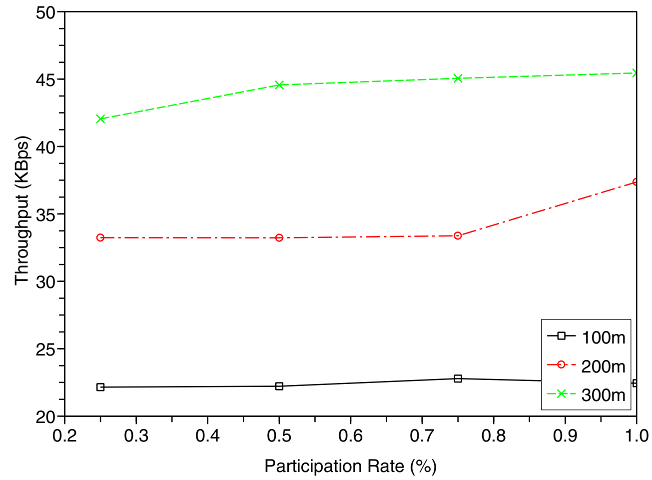

Fig. 7. Throughput as a function of participation rate at varying transmission ranges. There are 10 active vehicles sending at 100KBps and participation rate is fixed at 50%.

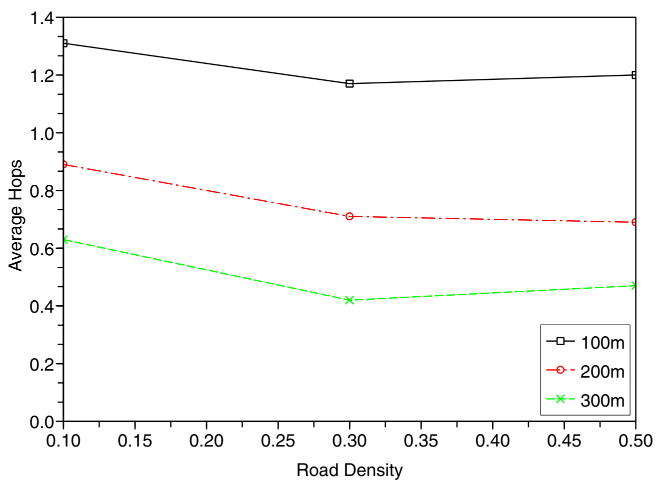

Fig. 6. Average number of hops as a function of density. There are 10 active vehicles sending at 100KBps and participation rate is fixed at 75%.

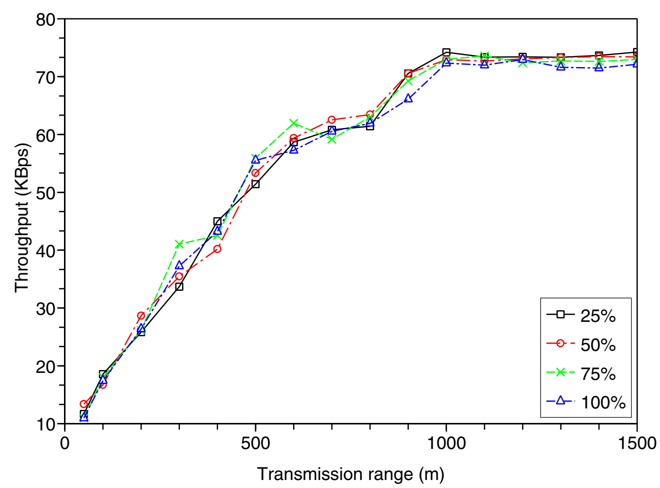

Fig. 8. Throughput as a function of transmission range at varying participation rates. There are 10 vehicles sending at 100KBps and density is fixed at 0.1.

transmission range is inversely proportional to the average number of hops needed to reach the access point as shown in Fig. 6. Intuitively it would seem that increasing transmission range would have an increasingly adverse affect on throughput as the number of collisions exponentially increases. However in our study we find that collision and interference with higher transmission ranges does not have as much of an effect as initially hypothesized. In fact, we observe that the major factor in increasing throughput was decreasing the number of hops between source and destination. This benefit more than offsets the adverse effect of increased interference at higher transmission ranges. Figure 7 clearly shows that, independent of penetration rates, higher transmission power results in higher throughput. This result is also mirrored in 10% and 30% traffic densities.

However increasing transmission indefinitely will not continue to yield higher throughput. We observe this in Fig. 8 which shows transmission ranges from 100-1500 meters. We find that throughput increases linearly until about 1000 meter range at which point increasing transmission range no longer benefits throughput.

Fig. 9 and 10 show 100% and 50% participation rates, respectively. It is clear that transmission range is positively correlated to throughput. But the results also show that there is no clear correlation between the traffic density and throughput. The throughput for relative traffic densities is similar. As mentioned in Section 4 the position-based routing protocol periodically broadcasts positioning information to surrounding vehicles. Since the number of participating vehicles is a function of the traffic density and participation rate, for any

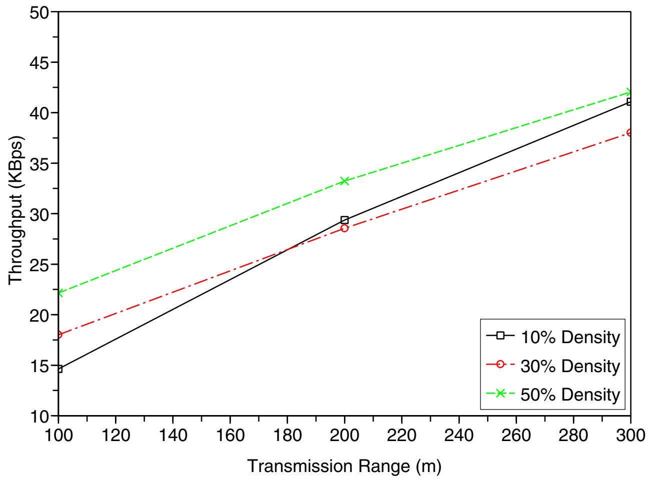

Fig. 9. Throughput as a function of transmission range at varying densities. There are 10 vehicles sending at 100KBps and participation rate is fixed at 100%.

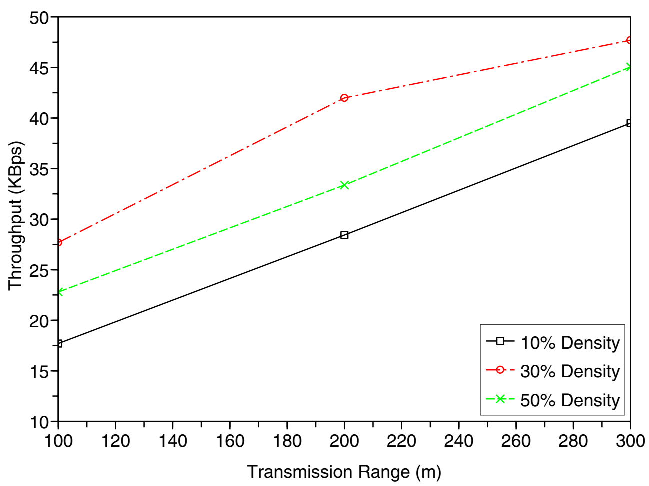

Fig. 10. Throughput as a function of transmission range at varying densities. There are 10 vehicles sending at 100KBps and participation rate is fixed at 50%.

given participation rate as density increases so does the number of participating vehicles. In turn, as the number of participating vehicles increase so does the amount of beaconing traffic since an increasing number of vehicles are broadcasting positioning information. This increase in traffic causes more collisions. However the loss due to interference does not seem to have a large impact on throughput. This is likely due to the small number of active vehicles tested, which are unlikely to saturate the 802.11 MAC layer. Future work will examine the effect of larger numbers of transmitters.

VI. Conclusion

The objective of this study was to understand the effect of tuning transmission power on UDP performance in multihop vehicular ad-hoc networks. In order to do this we developed an extensive simulation tool, which encompasses a strong network and vehicular traffic model. As a result of our simulations and analysis we found that performance in multihop VANETs is driven by the number of hops between the source and destination. Therefore increasing transmission range to its maximum is the response best suited to increasing throughput up to a certain saturation point, when using UDP. The knowledge gained from these studies is invaluable can be utilized in future studies to developing more reliable, more efficient, and more robust transport protocols for VANETs.

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