Analytical Investigation and Implementation of Carry and Forward based Routing Protocol for Vehicular Ad hoc Network

by

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Abstract

Recent research studies have recognized the applicability of carry and forward based routing in a vehicular ad hoc network (VANET), where packets are stored and carried by a moving vehicle until another vehicle comes into its transmission range and the packets are transmitted via wireless channel. This thesis explores several research topics concerning the use of a carry and forward approach in a vehicular network. In the first part of our research, we develop an end-to-end delay model in a unidirectional highway using vehicle-to-vehicle connectivity parameters that include the carry and forward approach which extends an existing catch-up time delay model for two disconnected vehicle clusters to multiple disconnected clusters on a unidirectional highway. Consequently, two distributions are newly derived to represent the number of clusters on a highway using a vehicular traffic model. The analytical results obtained from the end-to-end distribution model are then validated through simulation results. In the second part of our research, we present a fuzzy logic based beaconing system where beacon intervals are adjusted based on packet carried time, number of single-hop neighbors, and vehicles speed. It is common for vehicles in a VANET to exchange information by broadcasting beacon messages periodically. This information is required not only for routing protocols when making routing decisions, but also for safety applications. Choosing a suitable interval for broadcasting beacon messages has been considered a communication challenge since there will be a trade-off between information accuracy and channel usage. Therefore, an adaptive

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beaconing approach is needed so that vehicles can regulate their beacon rate based on traffic condition. Through simulation in a grid model and a realistic scenario, we are able to show that the fuzzy logic based beaconing system is not only able to reduce routing overhead and packet collision, but also decrease the average end-to-end delay and increase the delivery rate as well. The last issue of this thesis focuses on developing a proactive multi-copy routing protocol with carry and forward mechanism that is able to deliver packets from a source vehicle to a destination vehicle at a small delivery delay. It has been ascertained by the majority of researches in VANET that the carry and forward procedure can significantly affect an end-to-end delivery delay. Our approach is to replicate data packets and distribute them to different relays. The proposed protocol creates enough diversity to reach the destination vehicle with a small end-to-end delivery delay while keeping low routing overhead by routing multiple copies independently. The simulation results in an urban grid model show that the proposed multi-copy forwarding protocol is able to deliver packets at small delivery delay compared to a single-copy forwarding algorithm without having to rely on real time traffic data or flooding mechanism.

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List of Abbreviations

ABS	Adaptive Beaconing System
AODV	Ad-hoc On-demand Distance Vector
ASTM	American Society for Testing and Materials
ATB	Adaptive Traffic Beacon
BBR	Border Node based Routing
CDF	Cumulative Distribution Function
COG	Center of Gravity or Centroid
CPU	Central processing unit
DSR	Dynamic Source Routing
DSRC	Dedicated Short Range Communications
DV-CAST	Distributed Vehicular Broadcast
ETSI	European Telecommunications Standard Institute

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FBI	Fixed Beacon Interval
FCC	United States Federal Communications Commission
FLS	Fuzzy Logic System
GPCR	Greedy Perimeter Coordinator Routing
GPS	Global Positioning System
GPSR	Greedy Perimeter Stateless Routing
GyTAR	Greedy Traffic-Aware Routing
IDM_LC	Intelligent Driver Model with Lane Changing
IEEE	Institute of Electrical and Electronics Engineers Inc.
ITS	Intelligent Transportation Systems
IVC	Inter-Vehicle Communication
MAC	Media Access Control
MANET	Mobile Ad hoc Network
MMSE	Minimum Mean Square Error
MOPR	Movement Prediction-based Routing
MURU	Multi-hop routing protocol for Urban Vehicular Ad hoc Network

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NS-2	Network Simulator version 2
PDF	Probability Density Function
PHY	Physical
PMC	Proactive Multi-copy Routing
SCF	Single-copy Forwarding
SNR	Signal to Noise Ratio
SSE	Sum of Square Errors
UMB	Urban Multi-hop Broadcast protocol
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VADD	Vehicle-Assisted Data Delivery
VANET	Vehicular Ad hoc Network
VC	Vehicular Communication
WAVE	Wireless Access in the Vehicular Environment
WLAN	Wireless Local Area Network

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List of Symbols

C_L	the length between the first vehicle and the last vehicle in a cluster
D	The length of a road
$DPkt_n$	Data packets with id $n = 1 \cdots m$
$F_Y(y)$	Cumulative distribution function of a random variable Y
$f_Y(y)$	Probability density function of a random variable Y
I_i	Intersections available in a city map
I_c	The current intersection
I_{min}	Minimum beacon interval
I_{max}	Maximum beacon interval
L	Gap of between two neighboring vehicles
L_c	Gap between two neighboring connected vehicles
L_{uc}	Gap between two neighboring disconnected vehicles
λ	Traffic flow rate (vehicles/unit time)
λ_s	Vehicles density (vehicles/unit distance)
λ_{T_C}	Minimum mean square error between the exact distribution of T_C

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and an exponential distribution

M	The number of vehicle gaps in a cluster
nb_table	Table for the local neighborhood state information
m_copy	Table for packet replication information
N_c	Number of vehicle clusters on a highway
$N(t)$	Number of vehicles arrive at the highway during interval [0,t]
$P[y]$	Probability of an event y
$\Phi_Y(s)$	Characteristic function of a random variable Y
r	Vehicle radio range
R^2	Coefficient of determination
r_{I_i}	Road segments at Intersection i
$\overrightarrow{R}$	Road direction
S_{inter}	The spacing between the last vehicle of the leading cluster and the first vehicle of the following cluster
T	The arrival time of a vehicle at the highway and it is uniformly distributed at interval $(0, t]$
T_c	Time duration of a catch-up phase
T_f	Time duration of a forward phase
T_D	The sum of multiple catch-up times, T_c
V	the vehicles' speed and it is uniformly distributed at interval $[v_{min}, v_{max}]$
v_s	A source vehicle

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v_d A destination vehicle

v_k Neighboring vehicles

v_c A current forwarding vehicle

v_{nexth} A next hop vehicle

w_C Channel quality weighting

w_I Interval weighting

X_f The distance traveled by messages during a forwarding phase

X_c The distance traveled by messages during a catch-up phase

$X(t)$ Message propagation distance during $(0, t]$

$X'(t)$ Distance that the partition tail moves during [0,t]

Y The size of a cluster

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Chapter 1

Introduction

1.1. Background

Vehicular Ad hoc Network (VANET) is *vehicle to vehicle* (V2V) and *vehicle to infrastructure* (V2I) communications using wireless local area network technologies. The main idea of VANET is to provide continuous connectivity to mobile users while on the road, and to provide efficient vehicle-to-vehicle communications [1, 2]. In recent years, the research and development in this area has intensified due to several factors. One of the contributing factors is the potential advantages of VANET applications. V2V and V2I communications have enabled the development and implementation of a variety of applications, as well as providing a broad range of information to drivers and travelers. By integrating a vehicle's on-board devices with the network interface, various types of sensors and Global Positioning System (GPS) devices, the vehicle has the capability to aggregate, process and disseminate information about itself and

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its environment to other vehicles in the immediate vicinity that can be used for enhancing road safety and providing passenger comfort [3–5].

In addition, the advancements in computing and wireless communication technologies have increased interest in "smart" vehicles, resulting in more vehicle manufacturers beginning to adopt the use of information and technology to tackle the issue of safety and the environment, as well as the comfort of their vehicles. A *smart vehicle* should at least be equipped with on-board units, also known as in-vehicle equipments, that are needed for communication. For inter-vehicle communication, it is assumed that a vehicle should have a central processing unit (CPU) that implements applications and communication protocols; a wireless transceiver for transmitting and receiving data packets or wireless signals; a GPS receiver for location and time synchronization information, and a human interface between the driver and the system [6–8]. In [8, 9], the authors described computing platforms for *vehicular communication* (VC) that are dedicated to VC functionality and independent from car processors and controllers. Car processors and controllers are normally used for tasks such as fuel injection, braking, transmission and car charging [8, 9]. However, VC computing platforms are independent from these vehicle power systems and are responsible for V2V and V2I communication protocols and applications. The VC computing platforms usually use information provided by the vehicle processors and controller and forward them to safety and driving efficiency applications [8].

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Another contributing factor in the increment of VANET studies is the commitment of national and regional governments to assign wireless spectrum and the wide implementation of wireless access technologies that provide the required radio interface to facilitate V2V and V2I communications between vehicles [5, 10, 11]. In 1999, the United States Federal Communications Commission (FCC) assigned the 75 MHz band of Dedicated Short Range Communications (DSRC) at the 5.850 - 5.925 GHz frequency for Intelligent Transportation Systems (ITS) application in North America, which is used for variety of services such as safety applications, real-time traffic management, traveler information and many more [3, 5, 11, 12]. In Europe, ETSI (European Telecommunications Standard Institute), which is responsible for the standardization in the telecommunication industry, has designated the frequency band between 5.885 – 5.905 GHz for ITS applications in year 2008 [3, 5, 11]. DSRC radio technology is built based on the IEEE 802.11p standard, which is modified from the IEEE 802.11a standard since the latter is not sufficient enough to support inter-vehicle communication. The American Society for Testing and Materials (ASTM) modified the 802.11a standard to match the vehicular environment, and from this effort, IEEE standardized a new standard specifically for wireless access in the vehicular environment (WAVE) which is IEEE 802.11p with higher tolerance to multi-path propagation and Doppler spread effects for moving vehicles [5, 13].

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