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Cross-layer congestion control model for urban vehicular environments

Mohammad Reza Jabbarpour [a,*], Rafidah Md Noor [a], Rashid Hafeez Khokhar [b], Chih-Heng Ke [c]

[a] Faculty of Computer Science & Information Technology, University of Malaya, Kuala Lumpur 50603, Malaysia
[b] School of Computing & Mathematics, Charles Sturt University, WaggaWagga, NSW 2678, Australia
[c] Department of Computer Science & Information Engineering, National Quemoy University, Jinning, Kinmen 892, Taiwan, ROC

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ABSTRACT

Congestion control in Vehicular Ad Hoc Networks (VANETs) is challenging due to limited bandwidth, dynamic topology and lack of central coordination. Unlike previous works which focus on congestion control with a fixed channel load threshold that causes bandwidth wastage, this paper presents a cross-layer congestion control model which consists of two modules to alleviate congestion in the congestion detection center. In first module, the event-driven messages are prioritized when an imminent danger or abnormal situation is detected on the road. Then in second module, the channel load threshold is assigned dynamically based on beaconing load and transmit power properties which results a satisfaction level of maximum load beaconing. As a result, it alleviates congestion problems and improves bandwidth usage in VANETs. Experimental results on different data-sets including various vehicle densities, distances and road maps with and without obstacles (e.g. walls and buildings) show that the proposed method outperforms existing methods in terms of the average delivery ratio, message reception probability and average delay of time. Moreover, the results prove that the performance of all approaches degraded significantly in realistic scenarios (i.e. scenario with obstacles) compared to unrealistic scenario (i.e. scenario without obstacles) due to wireless signal attenuation and absorption.
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1. Introduction

Vehicular Ad Hoc Network (VANET) is a self-organized network composed of mobile nodes connected with wireless links (Al-Sultan et al., 2014). In 2003, the Federal Communication Commission (FCC) (Clyburn et al., 2013) established the Dedicated Short Range Communications (DSRC) service, a communication service for private and public safety operating at a frequency range from 5.850 GHz to 5.925 GHz (Jiang and Delgrossi, 2008). IEEE developed a Wireless Access in Vehicular Environments (WAVE) standard, or IEEE 802.11p (IEEE802.11-Working-Group, 2010), to provide DSRC for VANET communication. A multi-channel spectrum system is developed in DSRC which encompasses seven channels and provides 10 MHz of bandwidth per channel wherein six are Service Channels (SCH) and one is identified as the Control Channel (CCH). SCH are utilized for non-safety and WAVE-mode messages or services, while CCH is used for safety messages (Mak et al., 2009; Amadeo et al., 2009; Kakkasageri and Manvi, 2014). To ensure the safety of drivers and passengers, a single 10 MHz wide channel is used to exchange safety messages and IEEE802.11-Working-Group (2010) offers a data rate ranging from 3 Mb/s to 27 Mb/s. Lower data rates have better resistance against interference and noises (Maurer et al., 2005), and are therefore preferred for safety messages and applications.

According to previous studies (Xu et al., 2004; Reumerman et al., 2005) and the final report of the Vehicle Safety Communications Project (Consortium, 2005), several messages should be sent from each vehicle every second to provide the desired accuracy for safety applications. Additional transmission repetitions can be considered to overcome the effects of packet losses owing to fading and collisions. Moreover, safety messages are large in size (from 250 bytes to 800 bytes) because of security-related overhead (e.g. digital certificates (Raya and Hubaux, 2007)). Thus, a simple computation (for instance, with 50 neighboring nodes which send 10,500 bytes packets per second) proves that the message load generated by beacons can greatly exceed the available bandwidth (Torrent-Moreno et al., 2009). For these reasons, there is a demand for a means of limiting and controlling load and congestion on the control channel, given that the exchange of safety messages can saturate the channel.

Several algorithms (Zhang et al., 2008; Khorakhun et al., 2008; Yang et al., 2004; Wischhof and Rohling, 2005) have been proposed to

* Corresponding author. Tel.: +60 176238395.
E-mail addresses: reza.jabbarpour@siswa.um.edu.my (M.R. Jabbarpour), fidah@um.edu.my (R. Md Noor), rkhokhar@csu.edu.au (R.H. Khokhar), smallko@gmail.com (C.-H. Ke).

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decrease the packet traffic congestion problem in VANETs. In this paper, we have classified congestion control mechanisms based on how they prevent congestion by fine-tuning the transmission parameters, and are called Reactive, Proactive and Hybrid congestion control mechanisms. A summary of these mechanisms along with their advantages and disadvantages is discussed in the following paragraphs, while, their related algorithms and taxonomy are discussed in Section 2 as Related Works.

Information about channel condition, such as channel load, is used by reactive algorithms to react to a congested channel situation. Considering the nature of these algorithms, the control actions are applied only after congestion has occurred. Consequently, some time is required to recover from a congested channel situation to normal conditions, which means that reactive approaches expose safety-related applications to the risk of not being able to fulfill their design goal, which is delivering their services without delay (Sepulcre et al., 2011b). In addition, fairness and packet prioritization, which are two important characteristics in vehicular networks, are difficult to achieve in reactive algorithms. As a result, reactive approaches cannot keep up with the fast changes in vehicular networks.

Proactive congestion control algorithms (Chuang and Kao, 2010; Hsu et al., 2011; Tielert et al., 2011; Viriyasitavat et al., 2010) utilize a model-based approach using information such as the number of nodes in the vicinity and data generation patterns to estimate which transmission parameters will not result in congestion, while providing the desired application level performance. In particular, such mechanisms typically apply a system model to estimate channel load under a given set of transmission parameters, and use optimization algorithms to determine the maximum transmit power and/or rate setting that adhere to a maximum congestion limit (Sepulcre et al., 2011b). Proactive approaches are suitable for vehicular environments, given that they are designed to prevent channel congestion. In vehicular environments, radio communication is primarily used for safety applications. However, radio performance can be severely threatened by a congested channel. In our study on congestion control mechanisms, we have observed that the proactive approaches have two main drawbacks. First is the requirement of a communication model that maps individual transmit power levels to determine the carrier sense range in order to estimate the expected load generated by other vehicles. Second is the necessity to accurately estimate, which is a demanding task, the amount of application-layer traffic generated within a specific period of time.

Hybrid congestion control is the third type of algorithm (Huang et al., 2010; Guan et al., 2012; Djahel and Ghamri-Doudane, 2012; Fallah et al., 2010) which attempts to take advantage of the reactive and proactive approaches, e.g. by adapting the messages rate re-actively and the transmission power proactively. Existing solutions can further be classified with reference to the means through which congestion is controlled, which is typically achieved by adjusting the transmission power, the packet generation rate, the carrier sense threshold or a combination of a subset of the transmission parameters. Hence, hybrid approaches sometimes suffer from the drawbacks of both approaches at the same time which degrades its performance.

In this paper, we have adopted a proactive approach which has a built-in model about the environment and tries to estimate traffic in the next time instances (control periods). In our proposed cross-layer congestion control model which is based on a dynamic threshold value that can be used to alleviate the above two mentioned drawbacks for proactive approaches (i.e. (1) the requirement of a communication model that maps individual transmit power levels to determine the carrier sense ranges and (2) the necessity to accurately estimate the amount of generated traffic via application-layer) by taking into account both the transmit power and traffic generation ratio simultaneously. We focus on the application, Medium Access Control (MAC), and physical layers in order to develop a cross-layer congestion control model. We have utilized a prioritization technique to differentiate various types of packets for more efficiency. As a result, we have achieved three main goals of this paper such as proposing a cross-layer congestion control model, improving bandwidth usage, and providing packets priority.

The rest of this paper is organized as follows: Section 2 discusses the characteristics of various congestion control algorithms in VANETs. Section 3 presents our proposed cross-layer model for controlling congestion in VANETs. In Section 4, different experiments are conducted to evaluate the performance of our proposed congestion control model. Finally, Section 5 concludes the paper with suggestions on future work.

2. Related work

As mentioned in the previous section, reactive algorithms act only after congestion happens in networks, whereas proactive algorithms prevent congestion. Hybrid algorithms take advantage of both reactive and proactive algorithms at the same time. Most of the proposed congestion control algorithms are discussed and classified based on the aforementioned classification in the following sections.

2.1. Reactive congestion control algorithms

Khorakhun et al. (2008) proposed a rate or power-based congestion control algorithm that uses a locally measured Channel Busy Time (CBT) ratio to fine-tune the packet generation rate or transmit power. This technique, owing to its local measurements, can neither prevent congestion in the wireless channel nor support different message prioritization classes. Furthermore, oscillations in the adjustment process cannot be prevented by the proposed algorithm. Consequently, transmit power is adjusted by different vehicles at various points in time. Hence, the surrounding vehicles that have not yet adjusted their transmit power observe a reduction of CBT ratio, which misleads them into modifying their transmit power correctly.

Subramanian et al. (2012) showed that a fixed carrier sense range and the non-existence of a guard area around transmitters are the main reasons for the low performance of IEEE802.11p MAC in high vehicle densities. They further investigated synchronous and asynchronous congestion control algorithms. The Decentralized Congestion Control (DCC) algorithm (European Telecommunications Standards, 2012) developed by the European Telecommunications Standards Institute is an asynchronous algorithm that uses different transmit parameters based on sensed channel load. In this algorithm, the transmit parameters do not differentiate their values at various congestion conditions. Thus, the above authors attempted to solve this problem using a Transmit Power Control (TPC) algorithm that assigns varying power of transmission values to different channel load conditions.

2.2. Proactive congestion control algorithms

Yang et al. (2004) proposed a Vehicular Collision Warning Communication (VCWC) based on packet generation rate to prevent congestion. VCWC utilizes multiplicative rate algorithm to tune the packet generation rate by using predicted performance based on suitable communication channel models. Meanwhile, the reception of redundant transmissions from neighboring vehicles is used in the decision-making rules to restrain safety message transmission.

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