Performance Measurement of a Dual-Channel Intersection Switch on the Vehicular Network*

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Abstract. This paper designs an intensively measures the performance of an efficient message switch scheme for the intersection area where routing decision may be complex due to traffic concentration, aiming at enhancing end-to-end delays and reliability for the information retrieval service in the vehicular network. Installed at the corner of an intersection, each switch node opens an external interface to exchange messages with vehicles proceeding to the intersection as well as switches the received messages via the dual-channel internal interfaces. Based on the slot-based MAC, at each slot time of internal interfaces, the sender node probes the channel status of the two different destinations and then dynamically selects the appropriate channel according to the probing result. The simulation result shows that the proposed scheme improves the delivery ratio by up to 18.5 % for the experimental channel error rate range as well as up to 8.1 % for the given network load distribution.

1 Introduction

According to the ongoing deployment of in-vehicle telematics devices and vehicular networks, wireless vehicular communications have become an important priority for car manufactures[1]. The vehicular network can be built in many different ways according to the variety of available wireless communication technologies, for example, infrastructure-based cellular networks, VANET (Vehicular Ad hoc NETwork), and roadside networks. Moreover, not just the vehicle but also diverse communication entities are participating in this network, including traffic lights, roadside units, sensors, gas stations, and many other facilities. Correspondingly, abundant application scenarios are now possible. In addition to the standard safety-related applications such as traffic accident propagation

* This research was supported by the MKE, Korea, under the ITRC support program supervised by the NIPA. (NIPA-2009-C1090-0902-0040)).
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D. Taniar et al. (Eds.): ICCSA 2010, Part III, LNCS 6018, pp. 11–20, 2010.

and emergency warning[2], information retrieval is very useful for drivers and passengers[3]. Specifically, a driver may want to know the current traffic condition of specific road segments lying on the way to his/her destination, query several shops to decide where to go, and check parking lot availability[4].

In the information retrieval service, queries must be delivered to the destinations and the result is sent back to the query issuer. A message proceeds to its destination according to a routing protocol each vehicle cooperatively runs. As each vehicle can move only along the road segment and static nodes such as gas stations and traffic lights are generally placed on the roadside[5], the message delivery path must trail the actual road layout[6]. Just as in the vehicle's path, intersection areas having many vehicles are important for the delay and reliability of message transmissions, because the large number of vehicles makes the routing decision very complex and raises intervehicle interference. Moreover, the carry and forward strategy is preferred to cope with the disconnection problem in the sparse vehicular network[7]. As will be described in the next section, this behavior further increases the complexity of message routing near the intersection area.

Definitely, there exists an intersection which has much more traffic than others and this hot area may be a bottleneck for both vehicle and data traffic. As an end-to-end path is highly likely to involve one or more such intersection areas, how to manage the communication in this area is very critical to the communication performance such as the transmission delay and the delivery ratio. In this regard, this paper is to design and measure the performance of a reliable and high-speed message switching scheme around the hot intersection area for the vehicular network, taking advantage of multiple channels. It is possible to create multiple channels in a cell in many available wireless protocols such as IEEE 802.11 series[2], Zigbee, and WirelessHart[8]. Existing researches have also pointed out that multiple network interfaces does not cost too much[9]. Moreover, the slot-based collision-free access scheme can be employed for predictable channel access, short delay, and reliability, while the probing-based access can efficiently reduce the effect of the channel error inherent in the wireless frequency channel.

This paper is organized as follows: After issuing the problem in Section 1, Section 2 describes the background of this paper and related work. Section 3 designs a wireless switch for intersection areas and performance measurement results are demonstrated and analyzed in Section 4. Finally, Section 5 summarizes and concludes this paper with a brief introduction of future work.

2 Background and Related Work

Jeju taxi telematics system keeps track of each taxi for the purpose of providing an efficient taxi dispatch service to customer[1]. To this end, each taxi periodically reports its GPS reading via the CDMA (Code Division Multiple Access) network, an instance of cellular networks serviced in the Republic of Korea. This system is rather an expensive vehicular network in the sense that every member taxi should pay the monthly communication fee. In the mean time, in November 2005, the U.S. Department of Transportation began to develop and test an integrated, vehicle-based crash warning system under the program of IVBBS (Integrated

Vehicle-Based Safety Systems)[10]. Here, data transmitted from the roadside to the vehicle could warn a driver that it is not safe to enter an intersection. Vehicles could serve as data collectors and anonymously transmit traffic and road condition information from every major road within the transportation network. After all, more vehicular networks are being deployed into our everyday life.

As for the wireless channel, the IEEE 802.11b standard specifies 11 channels operating in the 2.4 GHz band with 80 MHz of reusable spectrum[11]. Even though the number of simultaneous channels in a cell is limited to 3 due to the channel overlap problem, it is possible to create multiple channels from the wireless spectrum in a cell. In addition, Zigbee and Wireless HART (Highway Addressable Remote Transducer) support channels spaced by 5 MHz guard band, making it possible for each node to hop over channels to reduce the effect of channel errors[8]. The link layer is based on a TDMA (Time Division Multiple Access) style access scheme which runs on top of the time synchronization mechanism carried out continuously during the whole operation time by means of MAC PDUs. The time axis is divided into 10 ms time slots and a group of consecutive slots are defined to be a superframe. This access scheme can provide bounded access time for each node.

High mobility and nonuniform distribution of vehicles prevent the existing routing schemes from applying to the vehicular network. Quite a lot of researches have been recently conducted for vehicular networks to deal with such problems. Basically, the carry and forward strategy is preferred to cope with disconnection in the sparse network part[7]. Here, when a node cannot find a receiver, it stores the message in its buffer until it enters the range of a new receiver. Even though this scheme increases the transmission delay, it is better not to discard a message. This leads to a large traffic load around the intersection area. As a variant of carry and forward scheme, VADD (Vehicle-Assisted Data Delivery) exploits predictable vehicle mobility model in which vehicle movement is limited by the traffic pattern and road layout. Based on the traffic pattern estimation, a vehicle decides the best next node to forward a packet[12].

For the information retrieval method, VITP (Vehicular Information Transfer Protocol) has been proposed as an application-layer communication protocol, which is designed to support the establishment of a distributed, ad hoc service infrastructure over VANET[3]. The VITP infrastructure can be used to provide location-based, traffic-oriented services to drivers, using information retrieved from vehicular sensors and taking advantage of on-board GPS navigation systems. In this system, vehicular-service queries must be location-sensitive, specifying explicitly the target location of their inquiry. VITP communication entities follow a best-effort approach in their operation, while a VITP request is transported between protocol peers until some return condition is satisfied. The protocol peer that detects the upholding of the return condition, creates the VITP reply and posts it toward source-region and broadcast so that the issuer can receive even if it has moved. In the message exchange, many protocols can be exploited for information retrieval such as Zhao et al.'s V2VR, which select forward and backward proxies based on the mobility pattern of the vehicle[4].

3 Wireless Switch Design

Fig. 1 shows the basic idea of this paper. At the intersection, four static switch nodes from A to D are installed at each corner as shown in Fig. 1(a). The number of switch nodes is equal to the number of branches, whether they cross on the same plane or in different layers. Each switch node is bound to the vehicles heading for the intersection from the preassigned branch. For the sake of speeding up the transit time in the intersection area, each switch node opens an external interface to receive and send messages with other vehicles, while internally forwarding messages to an appropriate direction via the 2 additional channels not exposed to the vehicle. As contrast to the external interface that must follow the standard vehicular communication protocol, we can define a new protocol for the internal access. For the internal message exchange, this paper suggests that each node be connected to dual frequency channels which run slot-based MAC as shown in Fig 1. (b).

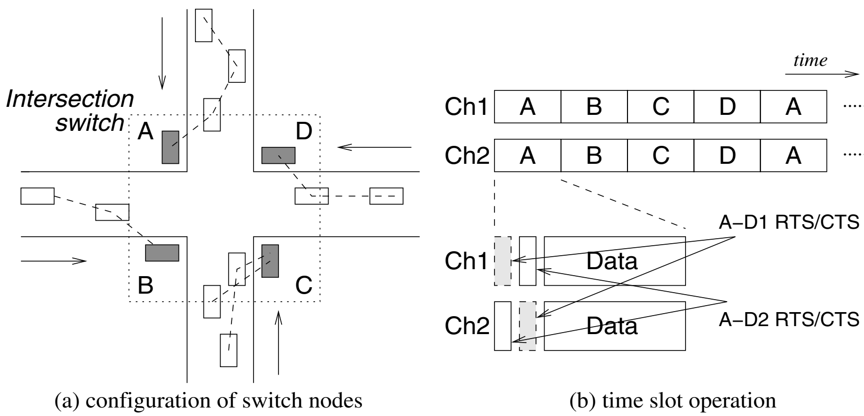

Fig. 1. Basic concept

When a vehicle having messages to send or relay approaches to an intersection, it checks if it can reach a switch node. If so, the message is sent directly to the switch node without contacting any other vehicles. Otherwise, the message is just forwarded to a vehicle in its moving direction just like in the normal ad hoc routing protocol. A switch node, receiving a message via the external interface, decides the next switch node to forward the message in its internal interface according to the final destination. In the intersection area, the complex routing among vehicles is skipped, reducing the number of relays and erroneous transmissions between moving vehicles. For this internal operation, each switch node transmits according to the TDMA manner to provide the predictable access. Even though this access demands that every node have the common clock, current GPS technology can easily achieve the global clock synchronization of reasonable accuracy[13]. So, many ad hoc networks also exploit the slot-based access scheme.

Many vehicles passing by the intersection area may cause channel interference, so an efficient method is necessary to cope with this problem. This problem can be solved by dual channels. The slots of two channels are synchronized, and two slots of the same time instance must be assigned to the same node. At the beginning of each slot, the transmitter node gets two messages having different destinations from its message queue. Our previous work has proposed a channel probing mechanism from two different nodes[14]. On the contrary, this paper makes a single node be assgined time slots on each channel and select the appropriate one. A channel probing result its corresponding action is similar in both schemes.

Let these two destinations be D_1 and D_2, respectively. The sender probes, for example, with RTS/CTS methods, D_1 and D_2 on the two channels as shown in Fig 1 (b). The transmission on the bad channel is meaningless not solely for the power consumption aspect. It may extend the instable energy and its duration. Table 1 shows the probing result and corresponding actions. As shown in row 1, D_1 on channel 1 and also D_2 on channel 2 are both in good state, D_1 and D_2 send as scheduled. In row 2, every channel status is good except the one for D_2 on channel 2. If we switch $< D_1, D_2 >$ to $< D_2, D_1 >$, both nodes can successfully send their messages. Otherwise, only A can succeed. In this case, the channel switch can save one transmission loss. Row 8 describes the situation that D_1 is good only on channel 2 while D_2 also only on channel 1. Switching two channels saves 2 transmissions that might fail on the regular schedule.

Table 1. Channel status and transmission

No.	Ch1–D1	Ch2–D2	Ch1–D2	Ch2–D1	Ch1	Ch2	save
1	Good	Good	X	X	D1	D2	0
2	Good	Bad	Good	Good	D2	D1	1
3	Good	Bad	Good	Bad	D1	–	0
4	Good	Bad	Bad	X	D1	–	0
5	Bad	Good	Good	Good	D2	D1	1
6	Bad	Good	Good	Bad	–	D2	0
7	Bad	Good	Bad	X	–	D2	0
8	Bad	Bad	Good	Good	D2	D1	2
9	Bad	Bad	Good	Bad	D2	–	1
10	Bad	Bad	Bad	Good	–	D1	1
11	Bad	Bad	Bad	Bad	–	–	0

X : don’t care

Each switch node maintains a message queue. The buffer space can be assumed to have no limitation, but it is desirable to discard a message which stayed in the buffer too much so as to obviate undue delay for the subsequent messages. After all, we assume that a message is automatically deleted from its queue when its waiting time exceeds the given discard interval. In addition, the routing decision outside the intersection area can be exploited by other work and there are many available schemes especially targeting at the urban area[15]. For example, VADD can cope with the situation that a vehicle moves after issuing a retrieval request. Finally, how to assign slots is not our concern, and we just consider the round-robin style allocation and assume that each slot is assigned to a switch node. There also exist some channel allocation schemes for the give traffic requirement[16].

4 Performance Measurement

We evaluate the performance of our scheme, focusing on the effect of channel switches, via simulation using SMPL, which provides a simple and robust library for discrete event trace similar to ns-2 event scheduler[17]. The main performance metrics are the delivery ratio and the access delay. The delivery ratio measures the ratio of the number of successfully delivered messages through the intersection area to the number of total messages arrived at the 4 switch nodes. The access delay is the time interval from the instant a message arrives at a switch node to the instant it gets out of the intersection switch. The average of access delays just takes the messages that have been successfully transmitted, so it is likely to increase when the number of successful transmissions increases. After all, this section shows the effect of the channel error probability, offered load, and the discard interval, one by one. In the following experiments, the message is assumed to arrive at each switch node according to the exponential distribution. In addition, for simplicity, each message fits a single time slot, making simple to estimate the traffic load. Moreover, every time is aligned to a slot length.

The vehicle distribution is taken from the Jeju taxi telematics system which keeps track of each member taxi[1]. Fig. 2 shows a snapshot of vehicle distribution on the real road network. This history is very useful for the vehicular

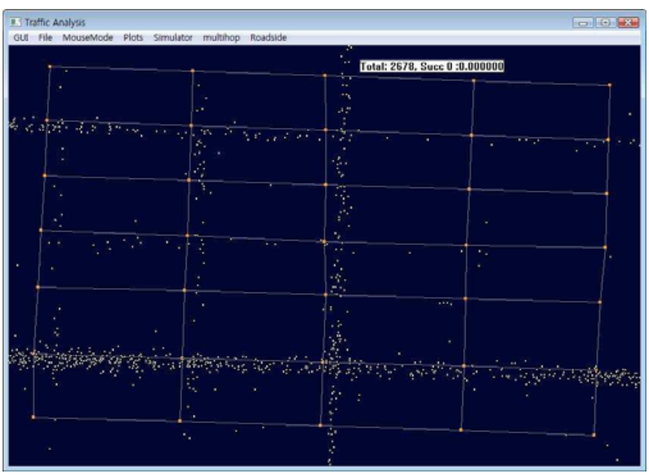

Fig. 2. Vehicle distribution at intersections

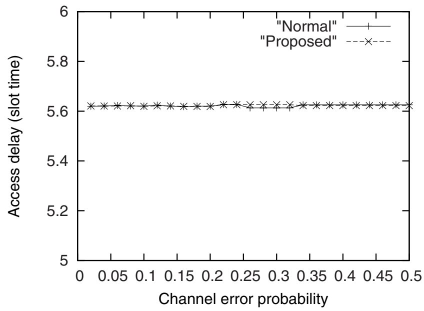

Fig. 3. Access delay at low load

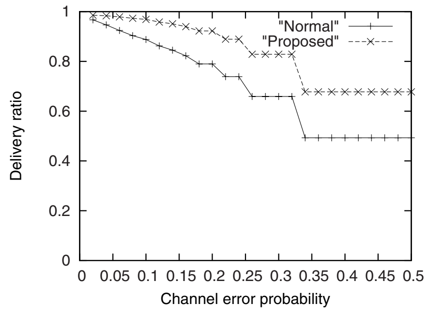

Fig. 4. Delivery ratio at low load

network design and the traffic pattern analysis. In this figure, the intersection is represented by a rectangle and the road segment is by a line, while the location of taxis during the specific time interval is marked with a small dot. The intersection area has more dots, which appear just along the road segment, even though the number of dots is different for each segment which meets at an intersection.

Fig. 3 and Fig. 4 show the effect of the channel error probability when the offered load is relatively low, namely, 0.5. The curve marked as *proposed* is the performance of the case of channel switching. The channel error probability is a probability that a channel is clean when a switch node is to send its message. This experiment assumes that a message is discarded if it is not served until 16 time slots from its arrival. Fig. 3 reveals that a message can exit the intersection area around in 5.6 time slots, that is, less than 1.5 round. In Fig. 4 the delivery ratio is almost 1.0 when the channel error rate is close to 0. At the higher error rate, we can achieve better improvement, as there are more cases channel switching is possible. When the channel error probability is greater than 0.4, the proposed scheme can improve the delivery ratio by up to 18.5 %.

Fig. 5 and Fig. 6 plot the effect of the channel error probability when the offered load is 1.0. On high load, a switch node can almost always find two

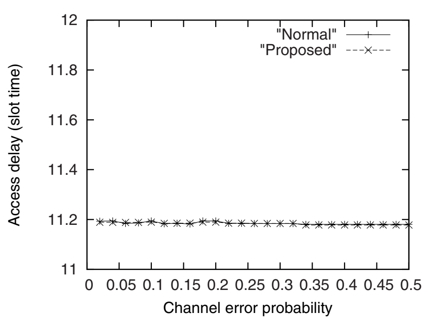

Fig. 5. Access delay at high load

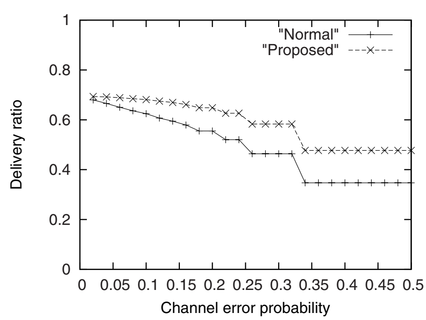

Fig. 6. Delivery ratio at high load

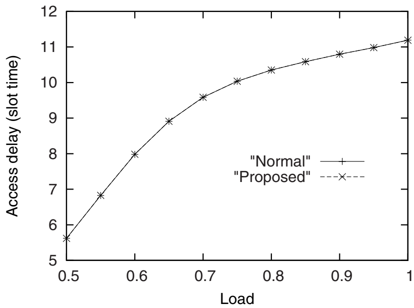

Fig. 7. Access delay vs. load

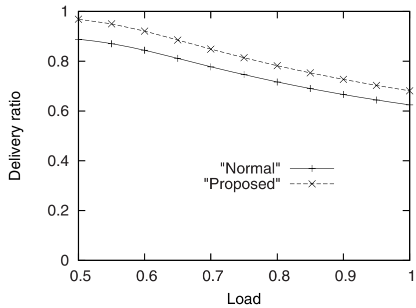

Fig. 8. Delivery ratio vs. load

messages having different destinations. As can be found in Fig. 5, the access delay for both cases stays at 11.2 time slots, namely, less than 3 rounds. This indicates that the discard interval can control the access delay quite well regardless of channel errors. When the channel error probability gets larger than 0.4, the proposed scheme can improve the delivery ratio by up to 13.0 %. Fig. 6 shows that both the delivery ratio and its performance gap are less than those in Fig. 4, indicating that the message discarded in the queue outnumbers that saved by the channel switch.

Fig. 7 and Fig. 8 demonstrate the effect of message load to the access delay and the delivery ratio, respectively. In this experiment, the channel error probability is set to 0.1 and the discard interval is fixed to 16 time slots. Fig. 7 shows that the access delays for two cases are almost same and the degree of inclination gets smaller after the load is 0.8, as more messages are discarded for the range of 0.8 through 1.0. In Fig. 8, the two curves show the constant gap for all load range, while the gap is 8.1 % at maximum, indicating that the early discard more affects the delivery ratio on higher load.

Fig. 9 and Fig. 10 show the effect of discard intervals. It can be simply expected that the shorter the discard interval, the shorter the access delay. Fig. 9 exhibits

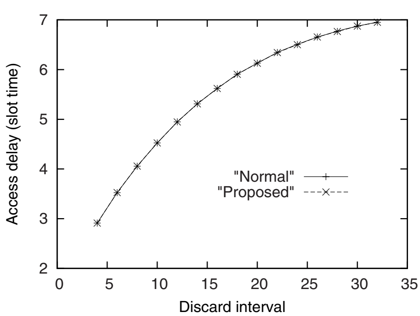

Fig. 9. Effect of discard interval

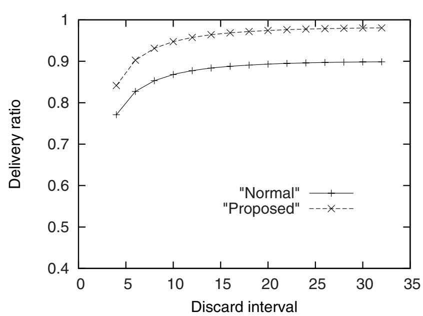

Fig. 10. Effect of discard interval

the largely linear increase of access delays according to the discard interval. Two curves also have no conceivable difference as in the other cases. However, Fig. 10 reveals that the effect of discard intervals is not so significant to the delivery ratio, less than 18 % over the interval range of 5 through 35. Two curves show a similar pattern, but the gap gets a little bit larger according to the increase of discard intervals. For all experiments, it can be pointed out by our experiment that the improved delivery ratio doesn't affect the transit time.

5 Conclusion

This paper has proposed and measured the performance of a message switch scheme for a hot intersection area in vehicular telematics network. Installed at each corner of an intersection, switch nodes cooperatively exchange messages according to the current channel status, speeding up the intersection transit time and improving the delivery ratio. The simulation result shows that the proposed scheme can improve the delivery ratio by up to 18.5 % for the given range of channel error probability, and 8.1 % for the given range of network load. This result comes from the fact that our scheme can avoid the complex routing and message interference in the intersection of intensive traffic. Next, dual channels can efficiently cope with channel errors. Even though such employment of additional equipments brings extra cost and loses the advantage of autonomous operations, access predictability, enhanced delivery speed, and better delivery ratio can compensate for the cost. In short, the wireless switch can be installed at the intersections, which have a lot of traffic especially in the urban area, to enhance the communication quality and reliability.

As future work, we are planning to assess the performance of our scheme with the real-life location history data obtained by the Jeju taxi telematics system[1] and analyze the end-to-end performance characteristics to revise our algorithm and test the diverse message scheduling policy.

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