An Efficient Fault Tolerant Distributed Path Recommendation Protocol for next generation of Vehicular Networks[§]

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***Abstract*—Several research studies have introduced an efficient and intelligent path recommendation protocols for vehicular networks. Communications among traveling vehicles and located roadside units (RSUs) have been utilized to investigate the traffic distribution over the road network. This helps construct the optimal path towards each targeted destination located on the road network. However, none of the previous proposed protocols in this field have specifically considered potential faults among the nodes of the vehicular networks or potential link failures. In this paper, we present a fault tolerant distributed-based path recommendation (TD-PR) protocol. Our protocol detects and tolerates faults occur among nodes and/or communication links. We present TD-PR protocol in this paper and report on its performance evaluation. Our simulation experiments show that TD-PR improves the success rate significantly over our previously proposed path recommendation protocol (ICOD). The success ratio is improved in roadside failure and link failure scenarios. In general TD-PR has better performance in terms of decreasing the traveling time and traveling distance compared to ICOD in these scenarios.**

***Index Terms*—Traffic efficiency, vehicular network, distributed path recommendation protocol, fault tolerance.**

I. Introduction

Traffic efficiency applications over the road network have been recently investigated using the vehicular ad-hoc networks (VANETs). These applications aim mainly at increasing the traffic fluency over the road network and at eliminating the highly traffic congested areas. Efficient path recommendation protocols, that consider the real-time traffic distribution over the road network, are popular examples of traffic efficiency applications. Centralized and distributed path recommendation protocols have been proposed in this field of research.

In centralized-based protocols, the server processor gathers the traffic characteristics of the entire road network. Then, it recommends the optimal path towards each targeted destination according to the following parameters: location of each vehicle, location of the targeted destination and traffic distribution over the road network [1], [2], [3], [4]. On the other hand, distributed path recommendation protocols relay on real-time communications among the roadside units (RSUs) located over the road network. Traveling vehicles report the traffic characteristics of surrounding road segments to the respective RSU. These located RSUs communicate together to construct an optimal path towards each destination located. These paths are constructed according to the location of each destination and according to the gathered real-time traffic characteristics of the investigated area [8], [9], [11]. Each traveling vehicle obtains the path towards its destination in a hop-by-hop fashion. At each road intersection traveling vehicles receive the best turn (i.e., next road segment) towards their targeted destinations.

Faulty node and/or faulty link over VANETs can affect the functionality, robustness and reliability of the path recommendation protocols. Faults over VANETs can be permanent, intermittent or transient [15]. To the best of our knowledge, none of the previous path recommendation applications have considered or handled any of theses fault problems specifically. As a consequence, in this paper we propose a fault tolerant distributed path recommendation (TD-PR) protocol. In TD-PR, failures either at located RSUs and traveling vehicles or at the existing communication links are detected first. Then, these failures are softly tolerated at each phase of the distributed path recommendation protocol. This enhances the functionality and the reliability aspects of the path recommendation protocol.

The remaining of this paper is organized as follows: in Section II, we discuss the previous path recommendation protocols and main fault tolerance mechanisms in VANETs. Then, we discuss the potential failures at each phase of our previous path recommendations protocol (ICOD) [9] in Section III. The details of the fault tolerant distributed recommendations (TD-PR) are presented in Section IV. Section V illustrates the performance evaluations of TD-PR protocol compared to ICOD for different scenarios. Finally, Section VI concludes the paper.

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II. Related work

In this section, we review the previously proposed distributed path recommendation protocols. Then, we investigate the fault tolerant mechanisms that have been proposed in the literature for VANETs.

A. Distributed Path Recommendation Protocols

Several research studies have selected the optimal path towards each destination targeted in downtown and urban areas [1], [2], [3], [4], [8]. These studies aimed mainly at avoiding highly traffic congested road segments and at finding the optimal path towards each targeted destination. Efficient path recommendation protocols enhance the traffic fluency and then decrease the travel time and the fuel consumption of moving vehicles.

Distributed path recommendation protocols produce more real-time and more accurate traffic congestion-avoidance recommendations. The path towards each destination is selected using cooperative communications among a set of distributed processors (i.e., RSUs) that are scattered allover the area of interest [8], [9], [11]. Our previous protocol (ICOD) [9] aim to recommend vehicles the accurate least congested path towards their destinations, in a dynamic and distributed manner. ICOD also flexibly considers the public common targeted services existence and the conditions of the road segments while selecting the desired path.

B. Fault Tolerant Mechanisms

Faults over VANETs can be either at the located nodes or at the existing links connecting these nodes. These faults can be classified as either permanent, intermittent or transient. The permanent fault will remain on the network, unless it is repaired and/or removed by external administrator. Intermittent fault is unpredictable, and it is difficult to diagnose. Finally, transient fault will eventually disappear without any apparent intervention. In general, three aspects are associated to the fault tolerance including: fault models, fault detection and diagnosis, and fault resiliency [15].

Fault detection is the first step to fault-correction and it is important for fault resiliency. Comparison approach [12], MM model [13] and broadcast comparison model [14] are some of the most popular approaches that have been proposed to diagnose and detect the fault scenarios. On the other hand, fault resiliency to tolerate the fault existence; this step aims at finding an alternative link or node to the failure one [15]. Moreover, redundant data over VANETs enhances the functionality of the proposed protocols and simplifies the fault tolerance [16].

In this paper, we aim at integrating the fault tolerance features to ICOD [9]. This feature is vital for enhancing the performance and functionality of ICOD.

III. Potential Failure Points in Distributed Path Recommendation Protocols

In this section, for completeness, we shall review briefly ICOD [7] then identify potential failure points at each phase of ICOD and then discuss.

A. Traffic Evaluation of Located Road Segments

During this phase, the real-time traffic characteristics of each road segment is evaluated and reported to the relative RSUs located over the road network. Travel vehicles cooperatively and efficiently evaluate the traffic speed, traffic density and estimated travel time of each road segment. Vehicles periodically advertise their basic traffic data including speed, location, direction, destination, etc. The road segment is divided into a set of virtual adjacent clusters, where the length of each cluster is less than the transmission range of travel vehicles. Receiver vehicles gather the basic traffic data of travel vehicles at each cluster and evaluate the traffic characteristics of such a cluster.

Reporting area is configured for each cluster, vehicles inside this area are responsible of reporting the traffic characteristics of the cluster to the neighboring clusters over the same road segment. The closest vehicle to the center of the reporting area is selected to transmit the traffic report of each cluster. After receiving the traffic report of neighboring clusters, each vehicle extends the boundaries of the evaluated area of the road segment. Then, vehicles in the reporting areas broadcast the accumulating evaluation and the boundaries of the evaluated area. The located RSUs at the ends of each road segment receive the evaluation of the entire road segment and record it to be used in the path construction process.

Possible Failures During the Traffic Evaluation: Several failures can appear during the traffic evaluation phase of ICOD:

1) Some vehicles fail to advertise the basic traffic data.
2) Some receiver vehicles miss important advertisement messages due to failure links over the communication network.
3) Selected vehicles in the reported areas fail to report the traffic characteristics of the configured cluster.
4) RSUs located over the road network fail to receive the evaluation report of surrounding road segments.

B. Destination Advertisement Message Broadcasting

In ICOD, we assume that each common targeted destination periodically broadcasts an advertisement message. Each group of destinations that are located close to each other register to a certain RSU., which is defined as an associated RSU to these destinations.

This RSU broadcasts the advertisement message on behalf of all destinations registered at its local database. The advertisement messages, that are initiated by associated RSUs, are vital to sense the traffic distribution over the road network and measure the dynamic changes of the traffic distribution. The advertisement message contains, identification of sender RSU, next hop, list of the registered destinations, travel time, travel distance and the round number ($nRound$) of sending the message. For each time the RSU sends an initial advertisement message, the first two fields are set by the identity of the associated sender RSU; meanwhile, the travel time and travel distance fields are set by zeros. The destination list field contains the identity of all destinations that are registered at the RSU. However, the last field is incremented for each round of the advertisement message broadcast. This last field is mainly used to detect faults that are caused by packets loss.

Possible Failure During Destination Advertisement*:* Two main failures can be detected during this phase:

1) Destinations fail to register at the closest RSU.
2) Associated RSU fails to broadcast the initial advertisement message.

C. Path Construction

After any located RSU receives an advertisement message, it checks the round number ($nRound$) field of the message. If $nRound$ less than the current recorded value related to this destination/destinations at the local database, the receiver RSU should drop the message and never consider forwarding it. However, in the case that $nRound$ in the received message is more than the current recorded value, the receiver RSU updates its local database for the advertised destination/destinations. This receiver RSU adds the required travel time and the required travel distance to arrive the road intersection, where the sender/forwarder RSU is located, to the current values of the second and third fields of the advertisement message. Then, it forwards the updated advertisement message towards neighboring RSUs.

On the other hand, in the case that the value of $nRound$ field of the advertisement message is same as the recorded value in the database of the receiver RSU. The latter RSU compares the values of the required travel time field of the advertisement message with the travel time field in the local database. If the travel time in the advertisement message is more than the travel time of the database, the RSU drops the message and does not forward it. Otherwise, the RSU updates its database regarding the received data. Then, it updates the received message and forwards the updated message towards the neighboring RSUs. This should be happened because, the arrived message recommends a path better than the recent obtained one.

Possible Failure During Path Construction*:* The potential failures in this phase can be in the nodes or in the available link among RSUs and travel vehicles:

1) RSUs fail to receive, process and/or forward the advertisement messages.
2) The communication link between two neighboring RSUs can be damaged while forwarding the message.
3) Traveling vehicles over long road segments fail to deliver the advertisement message between the RSUs located over the road network.

D. Path Recommendation

In this phase, the located RSU periodically broadcasts the recommendation report to the traveling vehicles. This report contains a list of destinations over the investigated area and the best next road segments (i.e., best turn at this road intersection) towards that destination. Each vehicle that is traveling towards the road intersection, where the sender RSU is located, find the next road segment to traverse towards its targeted destination from the recommendation report.

In some scenarios, the traveling vehicle cannot receive the recommendation report directly from the RSU because it is located outside of its transmission rang. In this case multi-hop communication among the traveling vehicles can deliver the recommendation report to traveling vehicles all over the road segment.

Possible Failure During Path Recommendation*:*

1) Located RSUs fail to broadcast the recommendation report.
2) Some vehicles fail to receive the recommendation report due to communication link failure.
3) In between traveling vehicles fail to forward the recommendation report all over the road segment.

IV. The Fault Tolerant Distributed Path Recommendations Protocol (TD-PR)

In this section, we introduce a fault tolerant distributed path recommendation (TD-PR) protocol. TD-PR detects the fault scenarios and aims at tolerating these faults efficiently at each phase of ICOD [7]. Unlike previously proposed fault tolerant protocols [17], [18], [19], we do not assume that there is no faulty node or no faulty link during the set up phase of the protocol. In general, TD-PR protocol handles all potential failures that are discussed and presented in Section III. In this section we present the fault tolerant phases of ICOD.

A. Fault Tolerant Traffic Evaluation

First, in the case where a certain vehicle has a problem to advertise its basic data over the road segment due to communication failure, camcorder or radar equipments can be used to physically detect the vehicle traffic characteristics. Using these equipments as an alternative solution to detect vehicles enhances the reliability and accuracy of the traffic evaluation phase.

In some scenarios, failures on the existing links prevent some vehicles from gathering the basic traffic data of some surrounding vehicles. In this case, some vehicles do not know about one or more of its neighboring vehicles. This problem can be, more significant in the scenario where the vehicle reported the traffic evaluation of the cluster does not know about some vehicles in such a cluster. In this scenario inaccurate traffic evaluation can be generated for the road segment due to inaccurate traffic evaluation reported for each cluster. In order to tolerate this failure and produce a more accurate traffic evaluation, the reported vehicle should validate the traffic data gathered about the cluster with some other vehicles inside such a cluster.

The reported vehicle sends a validation message to the closest vehicle to the center of the cluster. This validation message contains the gathered traffic data about the cluster in the local database of the reported vehicle. The receiver vehicle compares the contents of the validation message to its local traffic data gathered. In the case that the receiver vehicle has more data than the validation message, it sends an update message to the reported vehicle. The update message contains all traffic data that are missed by the reported vehicle. Otherwise, if the receiver vehicles does not have any extra data in its database more than the received data in the validation message, it sends an acknowledgement message. When the reported vehicle receives the update/acknowledgement message, it updates the report message according to the received data and broadcasts the report of such a cluster towards vehicles in the neighboring clusters.

B. Fault Tolerant Destination Advertisement

In order to make the destination advertisement phase more tolerant, each destination should register to more than one RSU over the road network. Each destination should choose the closest RSU as an associated RSU. The associated RSU of each destination should initiate the path construction process on behalf of each registered destination as illustrated in Section III.

If the associated RSU failed to initiate the advertisement message on behalf of its registered destination, another RSU that had a record of these destinations can initiate the message. This alternative RSU should wait for a predetermined period of time to receive the advertisement message from the associated RSU of the registered destination. In the case that, this RSU did not receive any forwarding advertisement message related to the destination registered, it sends a request message to its neighboring RSUs. The request message aims to verify whether any of the neighboring RSUs have received any advertisement message related to the destination registered. If any neighboring RSU have received a message related to this destination, that means the communication link between the associated RSU and the alternative RSU is failed. These surrounding RSUs reply the details about the destination towards the requested RSU. Otherwise, if none of the neighboring RSUs have received the message, this means that the associated RSU to this destination is failed to broadcast the advertisement message. In this case the alternative RSU should initiate an advertisement message on behalf of this destination instead of the original associated RSU. The fault tolerance destination advertisement process is illustrated systematically in Algorithm 1.

Algorithm 1: Fault Tolerant Destination Advertisement Algorithm

Data: D_i: Destination; AS-RSU: Associated RSU; ADV: Advertisement Message; AL-RSU: Alternative RSU; $T_{Threshold}$: Time threshold;
Req: Request Message;
$F-ADV$: Forwarding ADV message;
Rec: boolean value to indicate if the AL-RSU received the $F-ADV$ message or not;
R_{time}: Respond waiting time;
Rec_2: a boolean value to indicate if AL-RSU received a response message.

Each D_i registers to all close RSUs;
The closest RSU is selected as AS-RSU;
Other RSUs are AL-RSUs that checks if the AS-RSU initiate the path construction towards the destination correctly;
At each AL-RSU:
while *Waiting time in AL-RSU* $< T_{Threshold}$ **do**
  AL-RSU waits to receive a $F-ADV$;
  if *AL-RSU received* $F-ADV$ **then**
    Rec = True;
  end
end
if *! Rec* **then**
  Fault Detected;
end
if *Fault Detected* **then**
  AL-RSU sends Req message;
end
while *Waiting time in AL-RSU* $< R_{time}$ **do**
  if *AL-RSU received a response message* **then**
    REC2 = True;
  end
end
if *AL-RSU does not receive any response message* **then**
  AL-RSU broadcasts the ADV of D_i to initiate the path construction process;
end

C. Fault Tolerant Path Construction

ICOD assumes that a minimum traffic density is available at each road segment on the investigated road network. This assumption is essential for long road segments, as traveling vehicles are used to deliver messages between RSUs located at the ends of the relevant road segment. In order to release this assumption and to enhance the reliability of this phase more infrastructure (i.e., RSUs) is required over the road network. These RSUs are installed to deliver advertisement messages between the located RSUs at the ends of long road segments in the case that traveling vehicles failed to deliver these messages. Moreover, receive-carry-forward mechanism can enhance the reliability of this phase.

On the other hand, if any RSU located at a certain road intersection fails out, traveling vehicles that are crossing this intersection should cooperatively replace the broken RSU in terms of constructing the optimal path towards each destination. In order to achieve this, each vehicle should have the ability of processing, recording and forwarding the traffic data same as RSUs. Vehicles located close to the road intersection can receive the traffic evaluation reports of the existing road segments and the advertisement messages of adjacent road intersections. Thus, these vehicles should have the same database that should be recorded at the local database of the RSU located over the road network. If the RSU located at any road intersection was detected in a failure situation, the closest vehicle to the center of that road intersection should broadcast the updated advertisement message towards adjacent road intersections.

D. Fault Tolerant Path Recommendation

If any vehicle did not receive the recommendation report to select the best turn at the road intersection, it should send a request message asking for the recommendation report. If any neighboring vehicle/RSU received the request message, it should verify whether it is the best node to respond. The best node to respond is the closest node to the vehicle requested the recommendation. If the best vehicle to respond also did not receive the recommendation report, it should wait a certain period of time to receive the recommendation message.

For other receiver nodes, when they found that they are not the best node to respond, they set a waiting interval time to hear the best node forwarding the recommendation message. This interval time at each of these nodes is set based on the distance between the respective node and the vehicle requested. The closer the node to the requested vehicle is, the less the waiting time sets. If the interval waiting time at any of these nodes passed without hearing any forwarding of the recommendation message, this node should forward the recommendation message itself. The fault tolerance path recommendation process is illustrated systematically in Algorithm 2.

V. Performance Evaluation

In this section, we evaluate the performance of TD-PR compared to ICOD [7] when some failures occur among the existing nodes and/or links of VANETs. We investigate several scenarios where one or more RSUs fail to process or forward the advertisement messages during the path construction phase. An extensive set of simulation experiments using $NS-2$ [6] have been utilized to evaluate the performance of TD-PR. The parameters used are illustrated in Table I.

Algorithm 2: Fault Tolerant Path Recommendation Algorithm

Data: V_i: Travel Vehicle; N_j: an RSU or Travel Vehicle; $RecMsg$: recommendation message; $ReqMsg$: request message; W_{time}: waiting time threshold; $Hear$: a boolean value to indicate if N_j hear the $RecMsg$ being forwarded.

if V_i *! receive* $RecMsg$ **then**
    V_i sends $RecMsg$;
end
if N_j *the best node to respond* **then**
    if N_j *received* $RecMsg$ **then**
        N_j forwards $RecMsg$;
    else
        N_j wait to hear $RecMsg$ being forwarded;
    end
else
    N_j sets W_{time} based on its distance from V_i;
    while *time* $<$ W_{time} **do**
        if N_j *heard* $RecMsg$ *being forward* **then**
            $Hear$ = True;
        end
    end
    if *!* $Hear$ **then**
        N_j forwards $RecMsg$;
    end
end

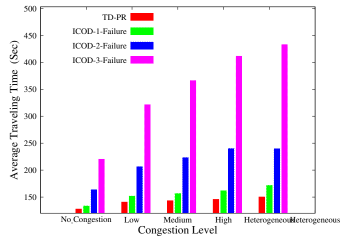
TABLE I
SIMULATION PARAMETERS

Parameters	Value
Road Segment Length (m)	200
Simulation Area (m X m)	1000 X 1000
No. of RSUs	16
Transmission Range (m)	250
Map Layout	4 X 4 grid-layout
No. of Road Segments	40 bidirectional
No. of Faulty RSUs	1, 2, 3

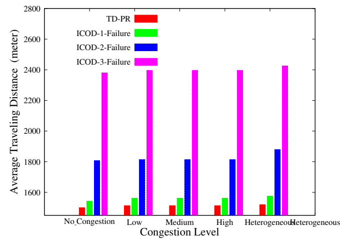
These experiments are investigated in a scenario where each RSU located at the road intersection try to find an alternative path towards three destinations A, B and C, located in a 4x4 grid-layout scenario.

In order to evaluate and compare the proposed protocol, we simulated different congestion level scenarios that have been proposed in our previously proposed work [7]: No (No congestion), Low, Medium, High and Heterogeneous congestion scenarios.

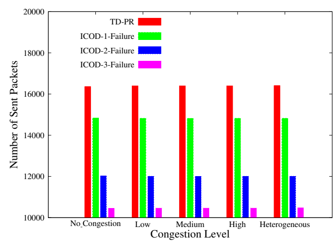
Figure 1 illustrates the performance evaluation of TD-PR compared to ICOD in case that one, two or three RSUs failed to process and forward the advertisement message. As we can infer from Figure 1(a) the average traveling time of vehicles is increasing drastically when more faulty nodes are existed on the system. The travel time is increasing for the scenarios where higher traffic congestion existed as well. Figure 1(b) shows that the average travel distance of vehicles is increasing drastically in ICOD by increasing the number of faulty RSUs as well. However, the travel time is slightly effected by the congestion level over



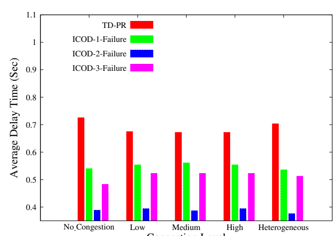
(a)



(b)



(c)



(d)

Fig. 1. The performance evaluation of TD-PR protocol: (a) average travel time towards each destination; (b) average travel distance towards each destination; (c) number of transmitted packets; (d) average delay of obtaining the optimal path at each road intersection.

the road network. TD-PR tolerates the different faulty scenarios where less travel time and travel distance are obtained (i.e., more reliable path is constructed). TD-PR obtains 10% lower travel time than ICOD with one faulty RSU, 30% lower travel time than ICOD with two faulty RSUs and 70% lower travel time than ICOD with three faulty RSUs.

On the other hand, TD-PR requires more delay time and extra transmitted packets than ICOD in these scenarios. As we can see from Figure 1(c) and Figure 1(d), the more the number of faulty RSUs in ICOD are, the less the delay time and the less the number of transmitted packets become. Fewer number of packets are transmitted in ICOD with faulty RSU nodes. This is due to the fact that faulty RSUs do not participate in the path selection process, and they do not send any packet over the network. TD-PR requires 40% of extra transmitting packets compared to ICOD with faulty nodes which consumes more bandwidth of the communication network. At the same time TD-PR requires 30% more delay time compared to ICOD to obtain the reliable path and to override the faulty nodes effects. This is because lower number of RSUs participate in the path selection process.

VI. Conclusion

In this paper, we have investigated the potential failure points in our previously proposed distributed path recommendation protocol (i.e., ICOD). Then, we have discussed tolerant solutions for each fault scenario. We have integrated the traffic efficiency applications and the fault tolerance mechanisms to introduce a fault tolerant path recommendation (TD-PR) protocol. Finally we have simulated different faulty RSUs over the downtown road network. From the experimental results, we found that TD-PR recommends vehicles with efficient paths in terms of travel time and travel distance. However, TD-PR requires more delay time and extra transmitted packets.

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