

Power-Aware Link Quality Estimation for Vehicular Communication Networks

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Abstract—The use of link quality estimates has been shown to improve multi-hop packet forwarding in wireless ad-hoc networks, and in particular in Vehicular Ad-Hoc Networks (VANETs). The link quality estimated at a receiver strongly depends on the transmitters' communication settings. As a result, adaptive transmission schemes such as power control can complicate the identification of reliable forwarders. In this context, this letter proposes and evaluates PoLiQ (Power-Aware Link Quality estimation), a novel technique designed to estimate the link quality in vehicular networks, taking into account the transmission parameters of each vehicle. This study shows that PoLiQ helps selecting reliable forwarders, and improves the performance of multi-hop vehicular communications.

Index Terms—Vehicular ad-hoc networks, link quality estimation, multi-hop routing.

I. INTRODUCTION

VEHICULAR networks are being investigated to improve traffic safety and efficiency through the dynamic exchange of information between vehicles, and between vehicles and infrastructure nodes. The IEEE 802.11p and ITS-G5 (European profile for Intelligent Transportation Systems) standards are used to transmit/receive periodic broadcast messages among vehicular nodes, formally known as WSM (WAVE Short Messages) or CAM (Cooperative Awareness Messages), but referred to as beacons in this letter for simplicity. Using beacons, vehicles can sense their local context and detect any potential danger or abnormal traffic condition. Relevant information can be distributed to distant nodes through dynamic multi-hop routing and dissemination schemes. Vehicular routing protocols generally exploit the vehicles' geographic position to select forwarders. For example, the greedy forwarding GPSR (Greedy Perimeter Stateless Routing) scheme [1] selects as next hop the neighboring vehicle that is closest to the destination. GSR (Geographical Source Routing) [2] solves some of GPSR inefficiencies through the use of digital road maps and the definition of route paths through which messages have to be forwarded. The use of real-time traffic information [3] has also been shown to increase the forwarding probability by avoiding disconnected route paths. The majority of protocols are based on the greedy forwarding concept that usually selects the farthest neighbor as next-hop. Such selection might result in unstable link connections due

to the high vehicular mobility and challenging propagation conditions. To select reliable forwarders, [4] estimates the links' stability based on the received packets' signal level. A different approach is adopted in [5] based on the *EPD* (Expected Progress Distance) metric, that estimates the links' quality using the number of beacons received from neighboring vehicles. *EPD* combines the estimated link quality and the neighboring nodes' progress towards the destination in order to select the best forwarder.

The reviewed link quality estimation methods do not consider the fact that all vehicles might not use the same transmission settings, e.g. transmission power and data rate. However, vehicles may transmit at different power levels based on their application requirements, and awareness or congestion control mechanisms. In this context, existing link quality metrics may result in the selection of unreliable multi-hop forwarders. To illustrate this problem, let's consider a scenario in which a vehicle A has received a data packet that needs to be forwarded towards a certain destination. Vehicle A has to choose the next forwarder between its neighboring vehicles B and C. Let's suppose that vehicle B uses a low transmission power (e.g. 10dBm), but is at a relatively short distance from A. As a result, vehicle A is able to receive all beacons transmitted by vehicle B. Let's now suppose that vehicle C uses a higher transmission power (e.g. 20dBm), but is at a higher distance from A. As a result, its higher transmission power also results in that vehicle A correctly receives all of its beacons. In this context, if we do not take into account the different transmission power levels, vehicle A would select vehicle C as next forwarder, since it provides the same link quality as vehicle B, but a higher progress towards the destination. However, if vehicle A uses a low transmission power (e.g. as a result of a congestion control policy), the data packet forwarded by vehicle A will not be correctly received by vehicle C due to its higher distance. To avoid this problem, this letter proposes PoLiQ (Power-Aware Link Quality estimation), a novel technique that estimates the links' quality in vehicular networks based on the periodic reception of packets from neighboring nodes and the knowledge of the vehicles' transmission settings. This is done so without piggybacking additional information in beacons. PoLiQ can be integrated with any link quality metric based on packet reception rates in which the transmission parameters are attached to the beacons headers. While PoLiQ is here presented as a method to support the selection of forwarders, it also partly addresses the larger problem of estimating the quality with which transmitted packets are received by surrounding vehicles.

The letter is structured as follows. Section II presents PoLiQ and the proposed link quality estimation method. Section III

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reports PoLiQ's performance when applied to two different multi-hop routing protocols. Finally, section IV summarizes the letter's contributions and potential of PoLiQ.

II. POWER-AWARE LINK QUALITY ESTIMATION

This study considers a vehicular network where vehicles periodically transmit beacons. In this network, the link quality experienced by vehicle i based on the beacons transmitted by vehicle j can be expressed in terms of the beacon reception rate R_{ji} . R_{ji} is computed as the ratio between the number of beacons vehicle i receives from vehicle j within a given time window, T_w , and the number of beacons transmitted by vehicle j during the time window. R_{ji} is strongly influenced by vehicle j transmission settings, for example its transmission power level Pt_j . Let's now consider that vehicle i has to forward a data packet, and wants to select the most reliable forwarder from its set of neighboring vehicles, N . Based on the reasoning previously exposed, the next forwarder must be chosen considering the link quality of the forward link, R_{ij} , instead of selecting it based on only the link quality of the reverse link R_{ji} . While R_{ji} is directly measurable by the forwarding vehicle i based on the beacons received from vehicle j , R_{ij} needs to be estimated. To this aim, PoLiQ proposes a new method for vehicle i to estimate the link quality R_{ij} with which each neighboring vehicle j would receive the forwarded data packet if selected as relay node. The estimation takes into account the transmission settings (in this letter, the transmission power level) of vehicle i and its neighboring nodes. The R_{ij} estimate for all $j \in N$ will then be used by vehicle i to decide which neighboring vehicle will be selected as next forwarder.

The proposed link quality estimate R_{ij} is defined as a function of the measured beacon reception rate, R_{ji} , the transmission power Pt_i of vehicle i , the neighbor's transmission power Pt_j , the visibility conditions Vis_{ij} between vehicle i and vehicle j (with $Vis_{ij} = Vis_{ji}$), and the CBT (Channel Busy Time) sensed on the wireless channel:

$$R_{ij} = f(R_{ji}, Pt_i, Pt_j, Vis_{ji}, CBT) \quad (1)$$

It is important noting that vehicle i knows the neighbor's transmission power Pt_j from the headers of the received beacons [6]. The visibility conditions between the two vehicles, here classified as Line of Sight (LOS) or Non-Line of Sight (NLOS), can be identified using digital road maps and the nodes' geographic position included in beacons. Finally, the CBT is defined as the fraction of time the channel is regarded as busy [6], thereby providing a measure of the channel load (the higher the load, the higher the probability to experience packet collisions), and can be measured at the wireless interface. The procedure to estimate R_{ij} is as follows:

- 1) Vehicle i computes R_{ji} based on the beacons it correctly receives from vehicle j in T_w and estimates the average received power level Pr_{ji} . Since vehicle i has only access to the received power level of correctly received beacons (i.e. the received power level of beacons received with errors and beacons that are not sensed is not available), the average received power level needs to be obtained analytically or empirically based on other

observable metrics. To this aim, a link quality function Q_{Link} relating the beacon reception rate and the average received power level for a given CBT and Vis_{ij} is employed to obtain Pr_{ji} , which will be later detailed:

$$Pr_{ji} = Q_{Link}^{-1}(R_{ji}, Vis_{ji}, CBT) \quad (2)$$

- 2) Assuming that an increment in the transmission power level is reflected by an increase of the same magnitude in the average received power level, vehicle i estimates the average received power Pr_{ij} for the packets it transmits towards its j^{th} neighbor in T_w as:

$$Pr_{ij} = Pr_{ji} + \Delta Pt \quad (3)$$

where ΔPt is defined as:

$$\Delta Pt = Pt_j - Pt_i \quad (4)$$

- 3) R_{ij} can then be obtained using the Q_{Link} function and the value of Pr_{ij} obtained in equation (3):

$$R_{ij} = Q_{Link}(Pr_{ij}, Vis_{ji}, CBT) \quad (5)$$

Using the estimated link quality R_{ij} rather than the measured R_{ji} allows for a more fair comparison of the link quality of the neighboring vehicles. The metric proposed in this letter takes into account the transmission power level of neighboring vehicles, and assumes that the beacons always have a fixed size and are transmitted at the default data rate. However, it could be expanded to consider data rates and beacon sizes.

Fig. 1 shows an example of the Q_{Link} function under LOS conditions, that relates the packet reception rate with the average received power level for different CBT levels (from $CBT = 0\%$ to $CBT = 60\%$). The figure has been obtained through simulations considering the simulation settings described in section III. For a given CBT, the average packet reception rate depends on packet collisions, the distance between two communicating vehicles (and hence the average received power level as a result of the pathloss), the shadowing and fast fading propagation effects. Fig. 1 was obtained by evaluating a wide range of distances between two communicating vehicles under different CBT levels. Fig. 1 also illustrates the described PoLiQ process to obtain R_{ij} when a $R_{ji} = 0.2$ is measured under $CBT = 60\%$ and $\Delta Pt = 8dB$.

The rapid variation of VANET conditions would hinder a reliable real time construction of Q_{Link} . On the other hand, deploying PoLiQ in real systems could be based on a set of pre-calculated Q_{Link} functions for a wide range of conditions (CBTs and visibility conditions); pre-calculated Q_{Link} functions would only consume runtime memory. The Q_{Link} functions could be also cooperatively updated and refined based on the collection of packet reception statistics by multiple vehicles. Additionally, the visibility conditions could be derived considering also the presence of surrounding obstructing vehicles (and not only buildings) based on the positioning and vehicles' information included in CAMs.

III. PERFORMANCE EVALUATION

PoLiQ can be applied to any link quality metric based on packet reception rates. To demonstrate its benefits, PoLiQ is

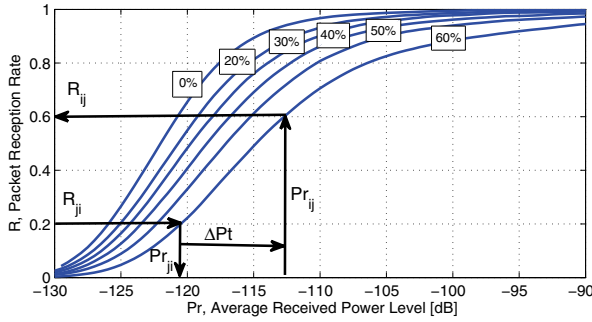


Fig. 1: Example of Q_{Link} function used in PoLiQ to obtain the estimated link quality metric.

combined in this work with the EPD metric in order to improve the selection of reliable forwarders. EPD uses ETT (Expected Transmission Time) to evaluate the link quality:

$$ETT = \frac{1}{(1-p_f)(1-p_r)} \frac{S}{B} \quad (6)$$

where p_f and p_r are the packet loss rates of forward and reverse links, respectively, S is the packet size, and B is the transmission rate. EPD selects the next forwarder based on the ETT link quality metric using the following equation:

$$EPD = \frac{d}{ETT^\alpha} \quad (7)$$

where d is defined as the progress distance of a neighbor towards the destination, and α is a weight factor adjusting the relationship between ETT and d . Without PoLiQ, the assumption of $p_r = p_f = 1 - R_{ji}$ is typically considered. The integration of PoLiQ in EPD is done by computing the packet loss probabilities of forward and reverse links following the proposed procedure, and then $p_f = 1 - R_{ij}$ and $p_r = 1 - R_{ji}$.

To test PoLiQ's capability to increase the reliability in the selection of next forwarders, the performance of two vehicular routing protocols is compared using the original EPD metric or the EPD metric integrating the PoLiQ proposal with $T_w = 5s$. In particular, the study considers the GPSR and LANE-RP (Lane-based Vehicular Density Estimation Routing Protocol) protocols. LANE-RP is a simple protocol proposed here that uses road topology maps. Differently from other approaches that select the shortest path towards the destination, LANE-RP forwards the packets over the streets with higher number of lanes. The protocol exploits the fact that streets with a higher number of lanes generally support higher traffic flows, and thus provide higher routing possibilities.

The performance is estimated in a Manhattan urban ns-2 simulation scenario consisting of a uniform grid of 6x6 blocks. All streets have two lanes, except a main avenue that has four lanes and traffic lights at the intersections. The vehicles' movement has been realistically reproduced through the microscopic SUMO traffic simulator. By default, the simulated scenario is characterized by a traffic density of 15 vehicles/km/lane. Vehicles communicate using the IEEE 802.11p standard at 5.9GHz, considering the channel model in [7] and using the PER (Packet Error Rate) curves for the V2V (Vehicle to Vehicle) urban channel reported in [8]. Beacons have a payload of 50Bytes and are transmitted with

a 2Hz frequency. Data packets have a payload of 95Bytes in GPSR and 303Bytes in LANE-RP; the higher size for LANE-RP is due to the need to include information about intermediate intersections. Data packets are generated every $T_d = 0.5s$ at the source node. Both beacons and data packets are transmitted with the IEEE 802.11p 6Mbps transmission mode.

The performance of PoLiQ has been analyzed considering that all vehicles transmit beacons and data packets with the same power level (*Fixed Pt* scenario), or considering that vehicles employ different power levels to transmit their beacons (*Variable Pt* scenario), while data packets are transmitted at a fixed transmission power. In the latter case, and to avoid any dependency to specific power control algorithms, the vehicles select their beacons' transmit power level randomly between 10dBm and 25dBm.

Fig. 2 shows the end-to-end data PDR (Packet Delivery Ratio) achieved by the GPSR and LANE-RP routing protocols in the *Fixed Pt* and *Variable Pt* scenarios. The performance is shown when applying the EPD metric and the EPD metric together with PoLiQ ($EPD+PoLiQ$). The x -axis of the figure represents the power level at which the data packets are transmitted. In the case of the *Fixed Pt* scenario both beacons and data packets are transmitted at the same power level. On the other hand, the *Variable Pt* scenario considers random power levels to transmit beacons. Fig. 2 does not include the $EPD+PoLiQ$ performance under the *Fixed Pt* scenario since the PoLiQ effect is only observed when vehicles have different transmission settings. This figure shows that the LANE-RP protocol always outperforms GPSR as a result of the selection of route paths with more dense traffic conditions. These paths present more potential forwarders and thus more routing possibilities. The results depicted in Fig. 2 clearly show that the performance of routing protocols incorporating the original EPD metric is importantly degraded when vehicles have different beacons' transmission power levels compared to the *Fixed Pt* scenario; the PDR reduction is more significant at low data transmission power levels. This degraded performance is due to the fact that EPD wrongly estimates the quality of the neighbors' links when vehicles transmit beacons with variable power levels. In particular, EPD tends to estimate that the nodes transmitting beacons at higher power levels always offer better quality links. Consequently, these nodes are usually selected as next forwarders. Since these neighbors may not necessarily provide reliable links at a different transmission power level, transmission errors frequently occur when a lower power is employed to forward the data packets. The integration of PoLiQ with the EPD metric provides nearly the same PDR level as when all vehicles transmit at the same power levels. These results show that PoLiQ can successfully assist in the forwarder selection in scenarios with variable power levels.

The selection of unreliable forwarders does not only affect the end-to-end data delivery, but also the communications overhead on the wireless channel which has been identified as a critical aspect to ensure the scalability of vehicular networks. Fig. 3 depicts the generated overhead, measured as the ratio between the number of data packet transmissions conducted at the MAC layer and the data packets successfully delivered to the destination. Fig. 3 shows that the selection

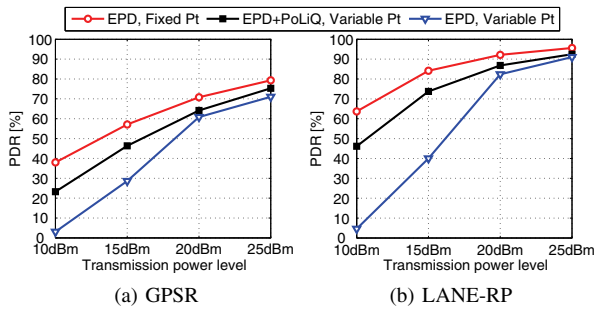


Fig. 2: End-to-end Packet Delivery Ratio (PDR) under *Fixed Pt* and *Variable Pt* scenarios.

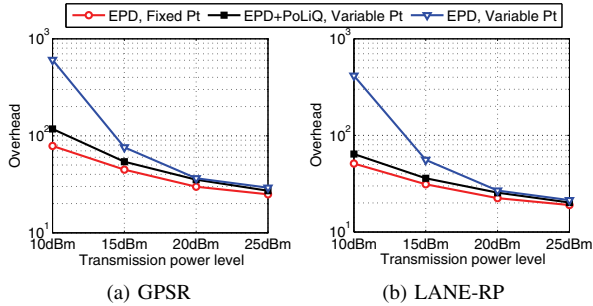


Fig. 3: Overhead under *Fixed Pt* and *Variable Pt* scenarios.

of unreliable forwarders when using the *EPD* metric over scenarios with variable transmission power levels results in a significant increase of the communications overhead. This is the case because the selection of unreliable forwarders generates continuous retransmissions at the MAC layer. In many cases, the forwarded data packet ends up being dropped at the MAC layer when the maximum retry limit is reached. This inefficiency is solved when integrating the PoLiQ proposal, which maintains the overhead at similar values as those experienced in scenarios with fixed transmission power levels.

To analyze the scalability of the PoLiQ proposal, its performance has also been tested in three scenarios with distinct traffic densities: Low (11 vehicles/km/lane), Medium (15 vehicles/km/lane) and High (18 vehicles/km/lane). In these scenarios, both data packets and beacons are transmitted at a variable power level to demonstrate the validity and potential of PoLiQ in more realistic scenarios, and given that the previous results already permitted the independent analysis of different fixed transmission power levels of data packets. Fig. 4 illustrates the end-to-end PDR obtained by the two forwarder selection techniques when they are combined with the GPSR and LANE-RP protocols. These results show that PoLiQ significantly increases the PDR compared to the original *EPD* metric, independently of the routing protocol.

IV. CONCLUSIONS

The performance of vehicular routing protocols strongly depends on the selection of reliable multi-hop forwarders. Several techniques have been proposed to identify reliable forwarding nodes based on the links' quality, generally estimated through the beacon reception rates from neighboring vehicles. However, these techniques do not consider the neighbors' transmission settings, and can consequently result

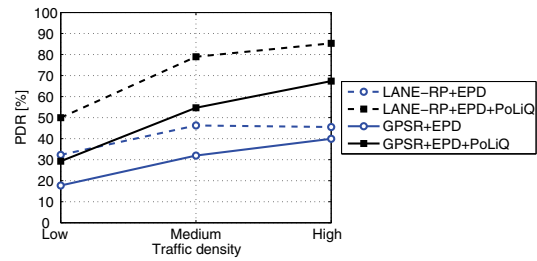


Fig. 4: End-to-end Packet Delivery Ratio (PDR) with variable power levels of beacons and data packets.

in inaccurate link quality estimates. In this context, this letter proposes PoLiQ, a novel scheme to reliably estimate the link quality with neighboring vehicles based on beacon reception rates and the neighbors' transmission settings. The conducted study has demonstrated that PoLiQ is able to increase the end-to-end PDR while reducing the communication overhead in scenarios where vehicles transmit at variable power levels. Although PoLiQ is here proposed for vehicular networks, it could actually be used with other multi-hop routing protocols based on beacon reception rates as long as nodes include their transmission parameters in their beacons. In addition, PoLiQ addresses a larger problem than just the selection of multi-hop forwarders, in particular, how can a transmitter estimate the reception quality of its messages. Future evolutions could include additional transmission parameters (e.g. data rate) or link quality metrics. It would also be of interest its evaluation under other environments and real-world experiments.

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