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Application of Cognitive Techniques to Adaptive Routing for VANETs in City Environments

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Abstract

The evolution of smart vehicles has widened the application opportunities for vehicular ad hoc networks. In this context, the routing issue is still one of the main challenges regarding to the performance of the network. Although there are multiple ad hoc routing proposals, the traditional general–purpose approaches do not fit the distinctive properties of vehicular network environments. New routing strategies must complement the existing protocols to improve their performance in vehicular scenarios. This paper introduces a novel intelligent routing technique that makes decisions in order to adaptively adjust its operation and obtain a global benefit. The nodes sense the network locally and collect information to feed the cognitive module which will select the best routing strategy, without the need of additional protocol message dissemination or convergence mechanism.

Keywords *VANET, . Adaptive routing, Cognitive techniques*

1 Introduction

The integration of communication support in vehicles in the form of car phones, cellular Internet access or GPS devices has focused a noticeable research interest in the recent time. However, direct vehicle-to-vehicle communication through ad hoc networks is a relatively new approach. As a particular case of ad hoc networks, Vehicular Ad hoc Networks (VANETs) also exhibit a highly dynamic nature, with a collection of special characteristics regarding mobility constraints, data traffic models and unreliable channel conditions. These properties pose new challenging research issues, including security issues [1].

Our approach sets the focus on a crucial component of vehicular networks: the routing protocol. The main requirement of routing protocols is to achieve a minimal delay with minimum consume of network resources. Although some of the routing protocols that have been developed for general–purpose ad hoc networks may be applied directly to vehicular networks, the unique nature of these networks usually leads to poor results. In consequence, it is obvious that vehicular networks need the definition of specific proposals that cope with the particular characteristics of this subclass of ad hoc networks.

In this paper we propose a novel cognitive routing technique that adaptively adjusts its operation to the changing state of the network. Given that the network conditions in ad hoc environments are extremely variable, and that this assumption is even more noticeable in the special case of vehicular networks in metropolitan scenarios, it seems that finding a single routing strategy that works properly in any situation is a utopic possibility. In consequence, we have performed an exhaustive study to analyze and differentiate those situations where specific routing strategies obtain better results. Our protocol uses a cognitive module to learn from these results and develops an adaptive behavior to fit its operation to the particular network state, which is sensed through local indicators.

The paper is structured as follows: Section 2 discusses the challenges of VANET routing in city environments and show the shortcomings of existing approaches. In Section 3 we introduce the particularities of vehicular ad hoc networks and their applications to analyze the design requirements of a potential routing protocol. Section 4 presents the com- prehensive analysis of the potential scenarios and proposes a new routing strategy based on a cognitive module, to later discuss the obtained results in Section 5. Finally, Section 6 summarizes our conclusions and outlines open issues.

2 Related work: routing in vehicular ad hoc networks

The large amount of literature demonstrates the high dependency of the message delivery in ad hoc networks on the routing protocol. The ad hoc routing issue has been extensively studied and there is a huge collection of approaches for the multi–hop self–organized message delivery. Nevertheless, the special features of vehicular ad hoc networks make a considerable difference against traditional ad hoc networks and, in consequence, the traditional general–purpose ad hoc routing protocols show a poor performance.

VANET networks are composed of vehicular nodes equiped with an on-board communication unit (OBU) and fixed nodes along the roads, known as road-side units (RSU). This composition generates different communication paradigms: vehicle-to-vehicle (V2V), vehicle-to-infraestructure (V2I) and infraestructure-to-vehicle (I2V). The communication particularities, which can be uni- or multi–cast depending on the application supported, the rapid changes of topology, the speed of the nodes and the mobility constraints question the existing protocols and suggest the introduction of specific strategies for a successful routing. Focusing on unicast routing, this section summarizes the most usual strategies to improve routing performance in vehicular ad hoc networks.

One of the main techniques applied to vehicular ad hoc networks makes use of mobility restrictions of vehicular ad hoc networks and the technology incorporated in the smart vehicles. **Geographic routing** [2–4] is supported on the use of street maps, traffic models and GPS devices to provide location information as address information to forward data packets towards the destination. Many studies sustain the advantage of the position–based strategy against traditional ad hoc routing schemes, but there are still some challenges to overcome, specially in urban environments. In these circumstances, nodes are more unevenly distributed because of the road patterns, and mobility constraints difficult signal reception for a direct transmission. In consequence, one of the main problems of this technique is the management of dead ends, when a packet cannot be forwarded to a closer node. Thus, this strategy must be combined with other approaches such as *perimeter routing* [5] to provide new routing alternatives and avoid dead-ends.

Another usual approach in order to improve the over- all performance as the network scales is clustering [6–8]. The distribution of the nodes into smaller groups prevents the interference between vehicles in crowded situations and helps the contention of message flooding. Traditional ad hoc clustering techniques are too short-lived for vehicular networks, and so, the main challenge is to produce efficient clusters that compensate for the extra protocol overload involved in creating and maintaining these clusters.

In **opportunistic forwarding** [9–11] data messages are stored until the opportunity of forwarding the information to any other node appears. Even if the data has already been sent, a copy of it may remain stored and waiting for the next opportunity in order to improve reliability. This technique has been successfully exploited in vehicular networks to disseminate safety messages while vehicles are moving along the roads. But it is inefficient when the data is to be sent to some specific destinations or there are strict delay restrictions, as there are, for example, in voice or video streaming.

Finally, **energy–concerned protocols** [12–14] adjust transmission power adaptively increasing it when the number of neighbors is low and decreasing it when the number of neighbors is large. Since power consumption is not a critical constraint in vehicular networks, this parameter can be penalized with the goal of improving the overall performance of the network. The objective is to increment communication probability when nodes find themselves isolated, but also to balance the competition for the radio transmission resources when the network is crowded.

The routing techniques summarized above provide an efficient solution for specific vehicular network scenario challenges, but it is difficult to propose a single strategy that fits the requirements of any potential scenario to reach proper performance levels for every kind of application running on the network. It is obvious that, apart from a suitable routing protocol, there is a need for access- control mechanisms and service differentiation to prioritize urgent traffic, maintaining good quality of service (QoS) levels for entertainment applications at the same time. But in any case, an adaptive routing protocol capable of adapting its behavior and switching between different routing strategies according to the highly dynamic net- work conditions would facilitate these tasks in the upper levels.

3 Key aspects of VANET city scenarios

This section gives a general overview of the distinguishing characteristics of VANETs, remarking the main challenges in the design of a general purpose routing protocol regarding to the performance of the network.

3.1 Network properties of a vehicular ad hoc networks in city scenarios

As a sub-class of the more general ad hoc networks, VANETs share some well-known features, such as short radio transmission range, self–organization, self-management and unreliable channel conditions. However, vehicular networks have also some distinctive network properties, mainly related to speed of the nodes, the behavior of the drivers and the mobility constraints of the scenario [15, 16]:

- **Highly dynamic topology:** the relative speed between vehicles is higher than in other ad hoc networks. In addition, and focusing on city environments, although the speed of the nodes is not so high as in highway scenarios, the metropolitan layout introduces more mobility constraints and obstacles that force changes in the topology.
- **Unstable channel conditions:** low antenna heights and the attenuation and reflection of all the moving metallic nodes cause adverse radio channel conditions.
- **Frequently disconnected network:** due to the topology changes, there is a high probability of network disconnection, specially with sparse nodes. Although this characteristic has more impact on highway than on city scenarios, the problem can be prevented by the use of fixed relay or access points along the roads.
- **Sufficient energy supply:** vehicular ad hoc networks exhibit no significant power constraints and this makes it possible to penalize energy performance in the trade- off to obtain better results in the rest of demanded requirements.
- **Mobility modeling and prediction:** the mobility and speed constraints of city environments favor the applicability of realistic movement patterns and the prediction of the future position of the vehicles.
- **Hard delay constraints:** although vehicular networks may also support entertainment applications, the main role of these networks is to provide safety–oriented services. This kind of application does not demand high data rates, but has strict delay requirements.
- **Interaction with on–board sensors:** the nodes are equipped with on–board technology, such as GPS receivers or control indicators, that can be used for routing purposes.

3.2 Applications of vehicular ad hoc networks

It is well known that there are two main types of service for vehicular ad hoc networks: *safety–oriented applications* and *comfort–oriented applications* [17], each one with differentiated requirements.

Safety–oriented applications exchange relevant information pieces to increase the safety of the vehicles and their passengers. This information may be presented to the driver or may trigger an actuator of an on–vehicle safety system. Examples of this kind of application are emergency warning systems, lane-changing assistants, intersection coordination and traffic signal violation warning. Applications of this class usually demand direct vehicle–to–vehicle communication due to the strict delay requirements. The emergency messages may be *event–driven* when triggered by unexpected situations such as accidents, breakdowns or obstacles. Whenever unsecure circumstances are detected, all the related information must be disseminated in order to relieve the potential consequences. On the other hand, these messages may also be *periodic beacons* [18] that are broadcasted to prevent and avoid future unsafe situations before they occur by making the vehicles aware of their environment.

Comfort–oriented applications have the objective of improving the travelling experience of the driver and the passengers through the increase of traffic efficiency, the optimization of the route to a destination and the provision of other entertainment services. Applications that fall into this class of service are traffic information systems, gas station location and price information services and other entertainment applications such as mobile Internet access and video-streaming.

In any case, safety–oriented applications are characterized by the broadcast of small pieces of information that must be prioritized against the traffic of comfort–oriented applications, specially event–driven messages. This kind of message does not demand high transmission rates, but has hard delay and reliability constraints. On the other hand, the rapid changes in the topology of the network affect mainly to comfort–oriented applications, where unicast and multicast routes are demanded. The routes established may go down even before they are used, and the network is always subject to a partition that may isolate some groups of nodes.

Considering the significant difference between the requirements of the potential applications and given that the performance of a routing protocol in vehicular net- works is highly dependent on the mobility pattern, the driving environment, the node density and many other factors, the design of a general–purpose routing solution that fulfills all the requirements seems to be a hard task.

4 Proposal of Glocal Adaptive Routing Intelligence (GARI)

This section introduces a Glocal Adaptive Routing Intelligence (GARI). This novel routing technique implements network state awareness through the sensing of a collection of local parameters, which are used to feed a cognitive mod- ule that selects the best routing strategy in each moment.

4.1 Description of the methodology

This section describes the design process of GARI routing protocol. It is generally accepted that proactive ad hoc routing protocols have the best performance when applied to most scenarios. The main idea is to take a well–known reactive routing protocol and modify its behavior in the scenarios where its performance degrades. The modification will entail a cognitive module that will monitor the conditions of the network in every node and will take the decision to switch to a pseudo-proactive operation mode to improve the performance of the routing protocol under certain situations. The decision–making process can be considered *glocal*, since each node collects data and decides locally, but the benefit is global as the performance of the whole network improves without an extra protocol interchange. The pseudo–proactive mode will be achieved by the generation of synthetic *route request* messages for all the active routes of the local node. A purely proactive protocol would flood route request messages all over the network to discover the whole topology. The pseudo–proactive mode only accomplishes the maintenance of the active routes to reduce the protocol overhead inherent to proactive routing protocols.

In consequence, the first step consists of the comparative study of different well–known ad hoc routing protocols in vehicular city scenarios in order to choose the best performing one. The same simulation results will be analyzed to identify the situations where the behavior of the selected protocol does not meet the expected level of performance. The next step is to select the locally measurable indicators that will provide the input for the sensing mod- ule of GARI. Finally, the bounds that divide the different service classes will be set using a classification algorithm and introduced in the cognitive module to serve as triggers for the operation mode switch. All these design decisions will be taken based on the simulation results of the exhaustive comparative study that is described next.

4.2 Comparative study of ad hoc routing techniques applied to vehicular city scenarios

For the purpose of the study detailed in this paper two idealized and generic scenarios shall be assumed: small–sized and large–sized. Table 1 summarizes the final configuration of each simulation composition, which is a permutation of these values in order to include realistic assumptions of real–world applications. The design of each setting was based on including three velocity rates (static, low velocity and high velocity), two node density values (low density and high density for sparse and dense traffic conditions), two data-traffic density values (few simultaneous connections and many simultaneous connections) and two routing strategies: proactive (Destination Sequenced Distance Vector – DSDV and Optimized Link State Routing – OLSR) and reactive (Ad hoc On demand Distance Vector – AODV and Dynamic Source Routing – DSR). The selected mobility model for the nodes is Manhattan, since it reproduces a metropolitan street layout through geographic restrictions on node mobility. This model uses a map composed of a number of vertical and horizontal streets. Each node is allowed to move along the grid and, at a street intersection, the node can turn left, right or go straight with certain probability. In the Manhattan model, there are additional constraints: the speed of a node in a step is correlated with its speed in the previous step and is restricted by the speed of any node preceding it on the same street.

Besides the varying parameters, there are other parameters that also model the scenario, but are maintained fixed. These are the parameters of the wireless communications model for the OBUs and the traffic pattern parameters (see Table 2).

For statistical reasons every simulation configuration is repeated 10 times with different mobility and traffic pat- tern files. This mobility and traffic patterns are randomly generated using different seeds inside the simulation block with the same configuration, but are reused in the same conditions with the other simulation blocks. The result is a collection of 960 differentiated simulations.

The simulation software employed is ns-2.34, traffic patterns are generated by the connection generator included in ns-2 and the mobility patterns are produced with BonnMotion-1.5 [19]. The simulation output obtained with this configuration is then processed to obtain statistically sound conclusions.

4.3 Statistical analysis of simulation results

This section describes the statistical analysis that supports subsequent design decisions. In order to assess the suit- ability of the two main routing techniques (proactive and reactive), the results of the simulation output described in the previous section were graphically analyzed com- paring their performance in each scenario. Figure 1 gives a global view of the operation of each routing technique in terms of the most usual metrics in each simulation area size.

Table 1 Modeling parameter<s for different considered scenarios

Scenario size	Small scenario 500m x 500m	Large scenario 1000m x 1000 m
Routing	AODV	AODV
Protocol	DSR	DSR
	DSDV	DSDV
	OLSR	OLSR
Mobility model	Manhattan	Manhattan
Velocity	0–1–5m/s	0–5–20m/s
No. of nodes	10 25	10 50
No. of simult. conn.	1–8 1–20	1–8 1–40

AODV exhibits the best behavior over proactive protocols in most of the configurations, showing the lower failure rate and the best goodput, together with a lower battery consumption. In addition, it also obtains a moderately good performance in end–to–end delay. But even if the delay results of AODV are not severely negative, when the application running over the vehicular network has strict latency constraints and the scenario is expected to scale, a proactive behavior should be considered.

Once AODV is selected as starting–point routing protocol, the second objective of this simulation study is to identify which of the modeling parameters are indeed relevant in the performance of the network. With this purpose, an analysis of the variance (ANOVA) study has been accomplished to perform statistical inference using simulation results as samples. Table 3 shows the outcome of applying an ANOVA analysis to the two scenario types described above. The highlighted cells point out the p–values that exceed the significance level indicating, hence, the lack of impact of the corresponding factor over the measured metric in that scenario.

Table 2 Fixed parameters

Transmission power	1.4w
Reception power	0.9w
Sense power	0.00000175 w
Initial energy	100.0 joules
Radio propagation model	Two ray ground
MAC	802.11b
Antenna	Omnidirectional
Queue length	50
Queue type	PriQueue
Traffic type	CBR
Packet size	512 bytes
Send rate	2 packets/sec

It can be observed that the speed of the nodes has no influence over the performance of AODV in the simulated scenarios. This surprising outcome can be justified studying the relationship between scenario size and trans- mission range of the antennas. The more reduced the area of simulation is, the higher probability for a receiving node to fall inside the transmission range of the sending agent. The mobility issue loses weight when most of the routes are one– hoped. Our experiments show that the speed of the nodes is a relevant factor in larger scenarios, such as freeway environments, that are out of the scope of this paper. The remaining factors, except for a few isolated cases, obtain a low enough p–value to consider that there is no reason to assume that do not entail significant difference for the measured metrics.

After the general impact of the factors is verified, a clustering analysis has been performed to check how this most significant modeling parameters are linked to the behavior of AODV running over all the simulated scenarios. The objective of the partition is to visually examine the results of the overall performance of AODV in terms of the classical QoS metrics of ad hoc networks: power–consumption, throughput, end-to-end delay, probability of error and protocol overload. The partition method employed to obtain the clusters shown in Fig. 2 is K-means clustering. K-means uses an iterative algorithm that minimizes the sum of distances from each object to its cluster centroid, over all clusters. The result is a set of clusters that are as compact and well–separated as possible. To avoid local minima, the clustering was processed 20 times, each with a new set of initial cluster centroid positions. Each point of the silhouette plot is a measure of how similar that point is to points in its own cluster compared to points in other clusters, and thus, a measure of how good the k–means clustering is.

As expected, Fig. 2 reveals the close relationship between the modeling parameters and the performance of AODV. The red cells belong to the scenarios where AODV has a satisfactory performance, while the blue ones correspond to those situations where a reactive routing protocol would exhibit a better behavior.

In consequence, GARI should operate as AODV in the scenarios colored in red and should trigger to the pseudo-proactive mode in the scenarios colored in blue.

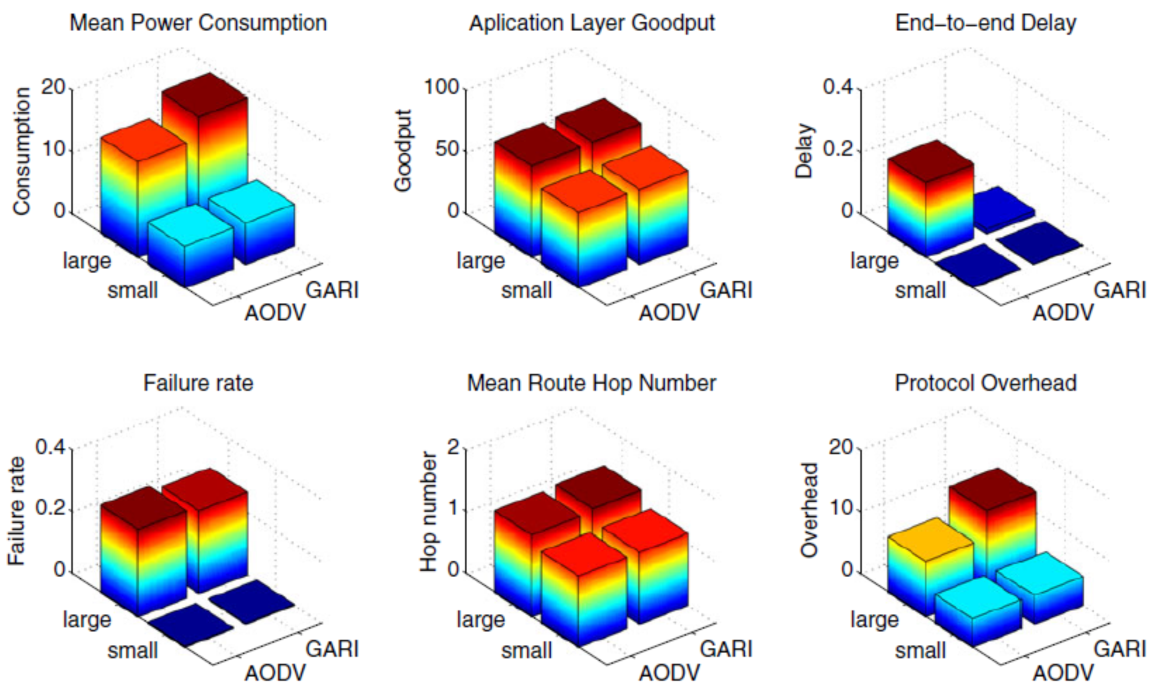


Fig. 1 Comparative analysis of routing protocols

However, values such as the total number of nodes of the network, or the instantaneous speed of the node are not available for the algorithms of the routing protocol. Therefore, these values must be estimated through a collection of indirect indicators that are measurable at network level. The selected indicators are route length, number of active routes in the routing table, number of errors received,

number of errors sent and number of neighbors and precursors. To avoid linear dependencies, a correlation analysis was carried out, resulting on four relevant indirect indicators: route length, number of errors sent, number of neighbors and number of active routes.

Finally, the indirect indicator data collected in the simulation traces serve as input for a new clustering process to verify that those indicators can be used to infer the changing characteristics of the network. The results shown in Fig. 3 validate the initial hypothesis and confirm that the cognitive module of GARI routing protocol can use indirect indicators as triggers for the decision making.

Table 3 Results of overall ANOVA analysis

Scenario	Metric	Node Density	Traffic Density	Velocity
Small	Mean e2e delay	0.000000	0.018629	0.801953
	Mean consumption	0.000000	0.000000	0.750622
	Mean goodput	0.000000	0.000000	0.983527
	Mean failure rate	0.253728	0.762905	0.293284
	Mean # route hops	0.000056	0.823398	0.903586
	Protocol overhead	0.000000	0.000000	0.986125
Large	Mean e2e delay	0.112537	0.284888	0.129997
	Mean consumption	0.000000	0.000000	0.958019
	Mean goodput	0.000000	0.000000	0.740673
	Mean failure rate	0.023223	0.836756	0.451990
	Mean # route hops	0.432937	0.003844	0.439611
	Protocol overhead	0.000000	0.000000	0.275466

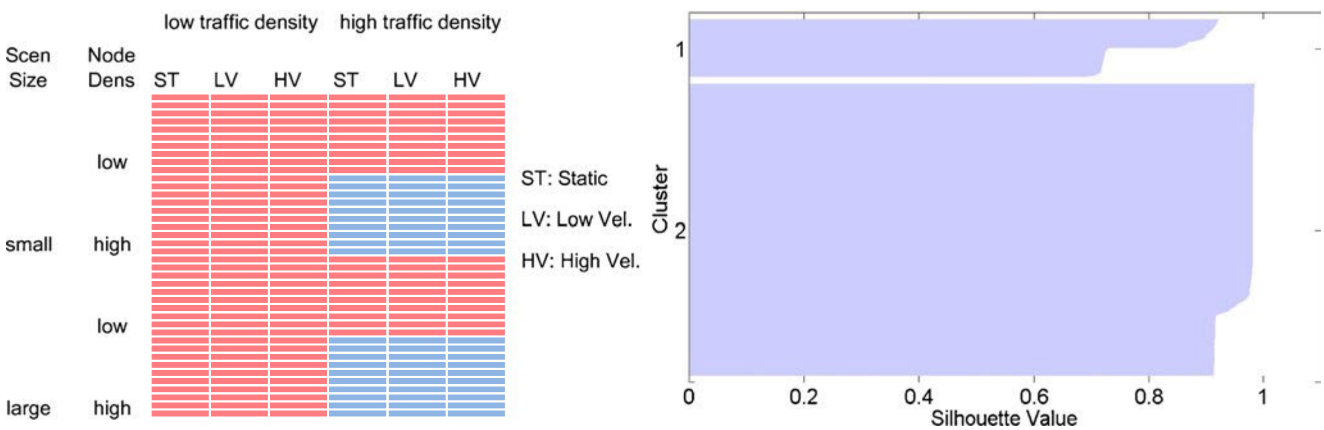


Fig. 2 K–means clustering and silhouette graphic of QoS metrics results from simulations

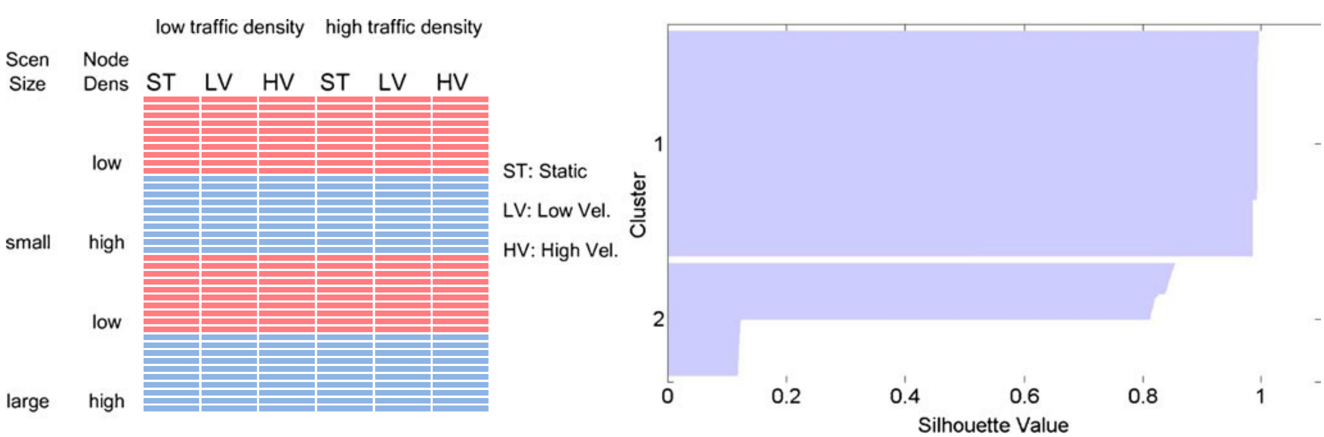


Fig. 3 K–means clustering of indirect indicator results from simulations

4.4 Design of the cognitive module

The objective of the cognitive module is to detect the situations when the on–demand routing strategy is not performing properly and to decide to switch to an alternative operation mode. With this purpose, GARI modifies AODV by the addition of a cognitive module that implements the periodic routine depicted in Fig. 4. GARI periodically senses the instantaneous values of the indirect indicators selected in Section 4.3 from local the protocol tables and counters, such as route table or neighbor table. Then, the decision module identifies which behavior class do those values belong to and applies the appropriate routing strategy in each time interval.

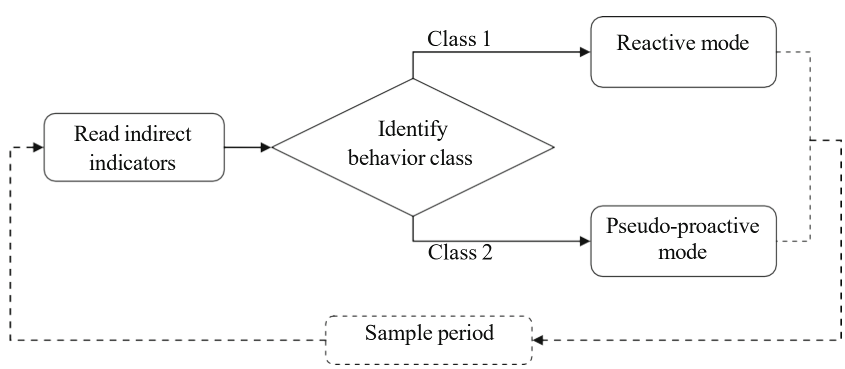
The challenge now is to design the decision module that makes the routing protocol capable of adapting its behavior to the instantaneous and local conditions of the network. This design involves two phases: an off–line *training phase* and an on-line *decision phase*. The training phase makes use of the results of the statistical analysis to classify the situations when the reactive routing strategy is not effective and should be switched to pseudo-proactive mode, and is per- formed off-line to release the nodes from a computational effort that will increment the end-to-end delay. This part of the design has been performed through a *discriminant analysis*. The discriminant analysis is a classification method whose output determines the linear bounds between the on-demand zone and the pseudo-proactive zone in terms of the indirect indicators described in Section 4.3: route length, number of errors sent, number of neighbors and number of active routes. The result of the classification process is the group of (1–3):

$$f12 = 66.34 + 0.01 * hopC - 1.84 * errorC \\ -0.45 * routeC - 4.09 * neighborC \tag{1}$$

$$f13 = 257.42 + 2.27 * hopC - 7.89 * errorC \\ -2.03 * routeC - 9.59 * neighborC \tag{2}$$

$$f23 = 191.07 - 2.21 * hopC - 6.05 * errorC \\ -1.58 * routeC - 5.50 * neighborC \tag{3}$$

Fig. 4 Operation of the cognitive module of GARI



where *hopC* stands for the number of route hops, *errorC* for the number of errors sent, *routeC* for the number of active routes and *neighborC* for the number of neighbors of the node.

Finally, the pseudo-proactive operation mode must be defined. In a pure proactive routing protocol, each node must maintain a route to all the nodes of the network just in case they are needed anytime. The cost of this strategy, in terms of protocol overhead and memory resources is too high to be effective. We propose a pseudo–proactive mode, where only the routes stored in the local table of each node are proactively maintained in order to moder- ate protocol overhead. The maintenance mechanism forces *route–request* messages for all the active routes with the objective of finding better routes for the ongoing transmissions. Since the routes in vehicular networks, and especially in urban environments, tend to be short–lived, the objective of the pseudo–proactive mode is to find a better routing alternative on–the–fly before the current one fails. Minimizing route ruptures will improve application good- put while reducing end–to–end delay, due to the avoidance of route repair mechanisms.

It is important to remark that this process is absolutely local and distributed. The cognitive module is fed by the information sensed by the node itself, not needing any peri- odically updated information from the neighbors. Then, the decisions are made in an independent and autonomous mode, without the additional exchange of protocol messages between neighbors to announce its new state. Both operation modes, reactive and pseudo–proactive, are compatible, i.e., some nodes may be operating in pseudo–proactive mode, while others remain operating in native reactive mode.

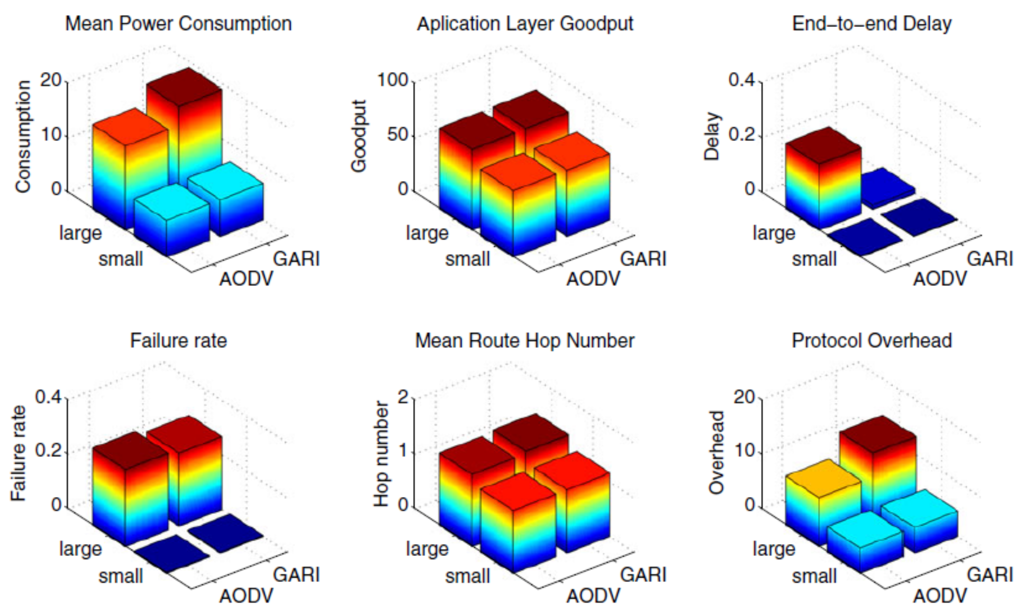


Fig. 5 Comparison between AODV and GARI

In summary, this new technique makes it possible to switch the operation mode of the routing protocol of a node from the data collected locally and needs no protocol message dis- semination for the convergence of the network, since both operating modes can coexist simultaneously.

5 Discussion of the results

GARI has been tested with a new collection of traffic and mobility patterns to analyze its performance and has been compared with AODV. Figure 5 shows the results of the simulation comparing the performance of both routing protocols.

The most noticeable improvement of GARI over AODV is the reduction of end–to–end delay. In addition, failure rate is also reduced and application level goodput is slightly improved. The cause the latter effect is that the route recovery mechanisms of AODV achieve to repair the broken routes and finally deliver the data packets. But, as these mechanisms are triggered after the failure is detected, the recovery time severely affects the end–to–end delay. GARI is able to perform a proactive route maintenance that anticipates route break downs and configurates better alternatives before the damage reaches the destination. In consequence, although GARI achieves a failure rate reduction of 30 %, the application layer output is only improved a 0.6 %. But the decrease of the failure rate and the increment of the mean route hop number support the fact that GARI has been able to recover failing routes faster than AODV, allowing to reduce the mean end–to–end delay a 95 %.

This effect of GARI is even more noticeable in metropolitan environments than in other configurations. The mobility constraints that imposes the grid layout, modeled by Manhattan mobility model for this study, causes the interruption of the transmissions more frequently than other configurations. Hence, this result is especially advantageous because the end–to–end delay metric is crucial for the usual applications supported in vehicular networks.

In exchange, the power consumption experiences a noticeable increase. However, as it has been mentioned in Section 3.1 this parameter is not a crucial factor in vehicular networks because the nodes are equipped with a sufficient battery supply.

6 Conclusions and future work

The growing interest over vehicular urban networks is generating a great amount of new applications with diverse requirements. The traditional ad hoc routing protocols do not fit the needs of urban vehicular networks that involve both vehicle–to–vehicle and vehicle–to–roadside communications, as well as strict delay constraints. In addition, the mobility limitations and high speeds increment the instability of the network and complicates the selection of a single routing strategy that performs properly in every scenario. Consequently, the adaptiveness turns out as a promising catalyst to improve the routing performance.

This paper has introduced GARI, a novel routing philosophy that adapts its operation to the potentially different and changing characteristics of vehicular city environments. GARI is able to fit the global performance requirements of a wider variety of applications, working in an absolutely dis- tributed and auto–organized manner. Even more, the new protocol needs no additional convergence mechanism to make all the nodes work with the same mode. Each node of the network can operate independently since both operation modes are compatible. In consequence, GARI is considered *glocal* because all the decision process is performed locally without extra protocol overhead, but the benefit is perceived globally with the general improvement of the network performance.

This first approach to glocal adaptiveness has made use of linear discriminant analysis with successful results, but further research will explore the possibilities of other non– linear alternatives.

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