Context-Aware Traffic Information Flooding in Vehicular Ad Hoc Networks

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Abstract

Traffic information in vehicular ad hoc networks is distributed through intelligent flooding mechanisms. To cope with superfluous forwarding usually rate- or spatial-adaptivity is introduced in the dissemination protocols. This paper focuses on spatial adaptivity techniques, which in certain cases should use context-aware information to achieve good performance. We propose an Integer Linear Programming (ILP) formulation to calculate on a digital map the Domain of Interest (DoI), the area where information about traffic jams is important for drivers. Afterwards, we analytically investigate the effect of this spatial context-awareness on traffic information dissemination. The behavior of a flooding protocol using the DoI knowledge is also explored through extensive simulations. Important characteristics on spatial adaptivity regarding the information dissemination strategies are concluded from the analytical and simulation results.

Key Words: Intelligent Transportation Systems, Traffic Congestion, Information Dissemination, Communication Protocols, Linear Programming, Optimization

1. Introduction

Traffic and Travel Information (TTI) [1,2] spreading in inter-vehicular networks is achieved by the means of a flooding mechanism [3,4]. To overcome network fragmentation the vehicles usually maintain and carry a copy of the packets [5–7], which is disseminated along the road segments. The frequency of subsequent transmissions will control the quality of the TTI reports, in terms of delay and accuracy. If the frequency of TTI transmissions is high, the time necessary for the information to reach the outer bounds of the geographic area is lower. The accuracy of TTI also varies in function of the amount of communication involved in the travel information gathering and transmission. Frequent information exchange leads to a more accurate picture about the traffic situation, but also to superfluous dissemination.

Superfluous forwarding can be reduced by using adaptivity in the flooding mechanisms [3,8]. Adaptivity can be introduced by controlling the frequency of information exchange (timely manner) [3,4] or limiting the dissemination only to areas where the TTI is really necessary (spatial manner) [8–11].

Spatial TTI dissemination can be achieved proactively, using a data-push model [8,9], or based on a data-pull model [10], when the information is obtained on-demand. In the first case the data is usually disseminated from the traffic incidents towards the outer in-bound road segments, while in the second case the data is pulled to the locations of interest on-demand. In both cases the question is how to control and limit the traffic information dissemination only to the places where the respective information is useful.

In this paper we investigate the problem of determining the Domain of Interest (DoI) of traffic jams. As we argue, the previous solutions fail to properly define the places where the TTI is useful. The effectiveness of these solutions will decrease without the use of additional mechanisms, which would provide context-aware DoI information about the traffic jams.

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In [11] the SPACE algorithm was proposed to calculate off-line the domains of interest on a digital map. This paper represents the continuation of [11], by proposing an Integer Linear Programming (ILP) formulation for the optimal DoI calculation. Analyzing and comparing the outcome of our ILP solution we draw important conclusions regarding the structure of the domains of interest. Then we enhance a TTI dissemination protocol [4] with context-aware feature, and show the advantages of our proposal by the means of simulations. Our results clearly show the advantages of spatial context-awareness in terms of channel utilization, while the travel time of vehicles remained unaffected.

The paper is structured as follows. Section 2 presents the related work, then in section 3 the ILP formulation for DoI calculations and extensive numerical analysis are presented. This is followed by the performance analysis of the TTI flooding protocol in section 4. Finally, section 5 concludes the paper.

2. Related Work

In [9] a protocol is presented, where drivers can subscribe to receive traffic information; this information is carried to the areas of interest by the TTI publishers. Since vehicles carry a replica of the information only to the places where uninformed subscribers are present, a spatial limitation of the TTI dissemination is achieved. In order to notify all the necessary subscribers, event replicas are generated and maintained in the subscription areas. Therefore, an appropriate number of replicas are necessary to disseminate the information to the corresponding areas of interest with a high delivery ratio. The replica owner will use the number of neighbor responses as an estimate of replica necessity in the respective area. However, due to the carrier selection and TTI replication mechanisms, there is not always guarantee that the information carriers will meet their subscribers. The successful outcome of the protocol highly depends on the topological context and the fine tuning of the system.

An approach for information dissemination to a set of well defined areas is presented in [8], taking into consideration the structure of the road network. Here the authors generate a propagation function, which encodes the destinations (target zones) and preferred routes into the message. The route that a message should take is driven by the directions of maximum decrease in the propagation function. The message originator does not encode a predefined trajectory with the propagation function; rather, the route is the result of the function evaluation at each routing hop. The computation and encoding of the propagation function is effectuated at the originator node; thus, this technique can be viewed as a special type of source routing [12]. Since the preferred routes are encoded in the packets, this method is vulnerable to topology changes, which could lead to frequent failures in TTI delivery. On the other hand, there is no presented method to calculate the propagation function, i.e., the locations where the information should be propagated. Therefore, this protocol is not ready to be applied in urban scenarios.

Traffic information is obtained by a pull-based protocol in [10], issuing a location-sensitive query along the route. The queries are routed towards their designated location of interest via the available inter-vehicular network. Upon arrival to the destination area, the queries are intercepted and processed by the local vehicular infrastructure. Then, through on-the-fly collaboration, a reply message is generated and sent back to the source location. These responses can help drivers to adjust their path while driving to some destination on a given route. The queries issued by the driver are responded by a set of vehicles collaborating to establish a virtual ad hoc server (VAHS), to resolve the incoming query and to send back the response. The VAHS is identified by the query and its target location area. Intermediary peers receiving queries can respond with a reply if their caches contain matching information. Unfortunately, there is no mechanism specified to calculate at what extent the queries, respectively the TTI reply/caching, should be propagated inside the road network. The authors present simulations, where the queries are propagated only to a randomly selected value of 400–800 meters inside the road segments. This means that in certain situations the information will not be received in time to calculate the proper by-pass route. Therefore, additional mechanisms are necessary to determine the critical points until when the queries must be propagated, i.e., from where the TTI information has to be gathered.

3. SPatially-Aware Congestion Elimination (SPACE)

As we pointed out above neither of the spatial ad-
aptivity techniques is applicable solely to cope with the problems regarding the areas of interest of a traffic jam. Apparently, additional (spatial) context information is necessary in order to further tune the performance of the TTI dissemination protocols. In this Section the problem of finding the optimal Domain of Interest (DoI) is formulated as an ILP problem, and analyzed through numerical results.

3.1 Example

First let us consider an example of one way roads from left to right (Figure 1), which represents a subset of a larger road network.

We assume that a vehicle enters the network at node 1, its destination is at node 10. The vehicle has route decisions at nodes 2, 3, 4 and 5, respectively. It can take either Route A, Route B, Route C or Route D to reach its destination. Route A is shortest and fastest; consequently, the vehicle takes the middle route in the default case. If route A at road segment 6-7 is congested, this information has to be disseminated throughout the road network.

Domain of Interest

The Domain of Interest (DoI) is defined as the set of roads, where the information about a traffic jam influences the route choice of the driver, i.e., the roads where the information should be flooded. At these places, the vehicles are still able to change their routes, without a drastic deterioration in their travel time. However, if the vehicle leaves a critical junction, enters in the zone of no return, where is no possibility to avoid the traffic jam, or only with a major increase in the travel time. Our scope is to optimize the area of DoI in order to reduce the amount of TTI flooding and at the same time to achieve as low vehicle travel times as possible.

Traditional flooding methods disseminate this information towards any directions. However, in the example this information is only interesting at the decision point 4 (optimized DoI), since the second best choice is route B. It is useless to deliver the TTI further than junction 4, as vehicles are heading towards junction 4, anyway. There is no sense in providing this information to the whole DoI, like (1,2,3,8,9). However, if both routes A and B would be congested, this information should be provided to an earlier decision point (junction 2, segment 1-2), where both routes can be avoided by a by-pass route C. This means that the DoI can also present characteristics varying over the time.

3.2 Problem Formulation

The road network (Figure 2) is represented by a directed and weighted graph \( G(V,E) \) with similar representation described in [13], using two types of edges \( E_r \) and \( E_t \) (\( E_r \) are directed edges representing a road between two intersections. One-way roads are represented with directed edges, while two-way roads with two opposite directed edges. The set of \( E_t \) represents the turning regulations, i.e., an edge from \( n_1 \in V \) to \( n_2 \in V \), where \( n_1 \) is the destination node of \( e_1 \) while \( n_2 \) is the origin node of \( e_2 \) \((e_1, e_2) \in E\), is included in the graph if and only if a turn \( e_0 \) on Figure 2) is allowed from \( e_1 \) to \( e_2 \). The weight of an edge represents the travel time on the corresponding road, or turning.

The event (traffic jam) is associated to a set of failed roads \( E_f \), which is a subset of the roads \((E_f \subseteq E)\). We assume that the set \( E_f \) contains the core of the problem, where the actual speed decreases to a fraction of the normal speed.

We also assume that an estimated Origin-Destina-

![Figure 1. Example road network.](image1)

![Figure 2. Representations of a road network.](image2)
tion (OD) matrix for the road network is known. The OD matrix \( OD(n,m) \) represents the average amount of vehicles traveling from node \( n \) to \( m \) in the OD matrix. If the OD matrix is not known then it can be assumed that it has uniform distribution, i.e., \( OD(n,m) = 1 \) for each \( n, m \in V \). We assume \( OD(n,m) = 1 \) in the remaining of the paper.

### 3.3 SPACE_ILP Algorithm

In this subsection the problem of finding the optimal Domain of Interest (DoI) is formulated as an Integer Linear Programming (ILP) problem. Although, solving an ILP by a solver has a long running time, we emphasize that this formulation has following motivations: the formulation gives an exact definition of the TTI dissemination problem and it allows a precise analysis of the problem compared to heuristic algorithms.

First, let us define the normal route of the vehicles. For each edge (pair of nodes) \((i,j), i, j \in V\), and origin and destination nodes \( n, m \in V \), we define the set of assignment variables, \( X = \{ x_{ij}^m \} \). The variable \( x_{ij}^m \) takes value 1 if edge \((i,j)\) is used in the shortest path from \( n \) to \( m \), otherwise 0. We apply the known flow conservation constraints, namely the property that no vertex, except the source and sink, of a flow network creates or stores flow (or more formally: the incoming flow is the same as the outgoing flow, or, the net flow is 0). The flow conservation constraints for the default routes are as follows:

For each \( j, n, m \in V \) where \( OD(n,m) > 0 \):

\[
\begin{cases}
\sum_{i \in V} x_{ij}^m - \sum_{k \in V} x_{ij}^m = \\
\quad 1 & \text{if } i = n \\
\quad -1 & \text{if } k = m \\
\quad 0 & \text{otherwise}
\end{cases}
\]  

(1)

Similarly, the by-pass route is defined for the vehicle. For each edge (pair of nodes) \((i,j), i, j \in V\), and origin and destination nodes \( n, m \in V \), we define the set of assignment variables, \( Y = \{ y_{ij}^m \} \). The variable \( y_{ij}^m \) takes value 1 if edge \((i,j)\) is used in the route from \( n \) to \( m \), otherwise 0. The flow conservation constraints for the by-pass routes are as follows:

For each \( j, n, m \in V \) where \( OD(n,m) > 0 \):

\[
\begin{cases}
\sum_{i \in V} y_{ij}^m - \sum_{k \in V} y_{ij}^m = \\
\quad 1 & \text{if } i = n \\
\quad -1 & \text{if } k = m \\
\quad 0 & \text{otherwise}
\end{cases}
\]  

(2)

Furthermore, in the formulation, both the normal and the by-pass routes are to be split in several pieces. For this, five more assignment variables are defined: \( a_{ij}^m \), \( b_{ij}^m \), \( c_{ij}^m \), \( d_{ij}^m \), \( f_{ij}^m \) (for each edge \((i,j)\), \( i, j \in V \) and origin and destination nodes \( n, m \in V \)) with following definitions:

- \( a_{ij}^m \) is 1 if edge \((i,j)\) belongs to the common part of the normal and the by-pass route, 0 otherwise.
- \( b_{ij}^m \) is 1 if edge \((i,j)\) belongs to the normal route after the fork of the normal route but before the jam, 0 otherwise.
- \( c_{ij}^m \) is 1 if edge \((i,j)\) belongs to the jam \((ij \in E_j)\), 0 otherwise.
- \( d_{ij}^m \) is 1 if edge \((i,j)\) belongs to the normal route after the fork of the normal route but after the jam, 0 otherwise.
- \( f_{ij}^m \) is 1 if edge \((i,j)\) belongs to the by-pass route while not to the normal route, 0 otherwise.

For an example of these definitions see Figure 1 with origin = 1, destination = 10, optimal route \((1,2,3,4,5,6,7,10)\) and by-pass route \((1,2,3,4,8,7,10)\). \( a_{ij}^m \) = 1 for roads \((1,2), (2,3), (3,4), \) and \((7,10)\), \( b_{ij}^m \) = 1 for roads \((4,5)\) and \((5,6)\), \( c_{ij}^m \) = 1 for road \((6,7)\), \( d_{ij}^m \) = 1 for all roads, \( f_{ij}^m \) = 1 for roads \((4,8)\) and \((8,7)\).

The above definitions are ensured by the following equations:

For each \((i,j) \in E\) and \( n, m \in V \) where \( OD(n,m) > 0 \):

\[
\begin{align*}
\sum_{i \in V} x_{ij}^m + \sum_{k \in V} x_{ij}^m &= 1 & x_{ij}^m \leq 1 \\
\sum_{i \in V} y_{ij}^m + \sum_{k \in V} y_{ij}^m &= x_{ij}^m \\
\sum_{i \in V} a_{ij}^m + \sum_{k \in V} c_{ij}^m + \sum_{k \in V} d_{ij}^m + \sum_{k \in V} f_{ij}^m &= x_{ij}^m \\
\sum_{i \in V} y_{ij}^m + \sum_{k \in V} y_{ij}^m &= a_{ij}^m \\
\sum_{i \in V} a_{ij}^m + \sum_{k \in V} c_{ij}^m + \sum_{k \in V} d_{ij}^m + \sum_{k \in V} f_{ij}^m &= b_{ij}^m \\
\end{align*}
\]  

(3)

(4)

(5)

Furthermore, the part of the default route after the jammed link \((d)\) has to be distinguished form the part before the jam \((b)\) with the following constraint:

For each \((i,j) \in E\) where \( OD(n,m) > 0 \):

\[
\begin{cases}
\sum_{i \in V} a_{ij}^m - \sum_{k \in V} f_{ij}^m = \\
\quad 1 & \text{if } c_{ij}^m = 1 \\
\quad 0 & \text{otherwise}
\end{cases}
\]  

(6)

For each road \((i,j)\) affected by the traffic jam \((ij \in E_j)\) set \( c_{ij}^m \) to 1 and \( y_{ij}^m \) to 0, while for each other (not
jammed) road \((i, j) \notin E_j\) set \(c_{ij}^m\) to 0.

Next, the assignment variables for the propagation region are defined and we formulate the fact that vehicles does not by-pass the jam until they receive a message about it, i.e., the normal route and corresponding by-pass route are to be the same outside the propagation region. For each edge (pair of nodes) \((i, j), i, j \in V\), we define the set of assignment variables, \(R = \{r_{ij}\}\). The variable \(r_{ij}\) takes value 1 if edge \(ij\) is included in the propagation region, otherwise 0.

In order to ensure a propagation region that reaches all places where normal and by-pass routes are to be forked, the following constraints are defined:

For each \(n, m \in V\) where \(OD(n, m) > 0\):

\[
r_{ij} \geq b_{ij}^m
\]

Finally, we define the objective by minimizing the weighted average of the length of all by-pass routes and the total length of the propagation region:

\[
\min \sum_{(i, j) \in E} \left( \alpha l_{ij} + (1 - \alpha) b_{ij} \right)
\]

where \(l_{ij}\) denotes the cost (length, travel time, etc.) of traveling on road \(ij\) while \(b_{ij}\) denotes the cost (e.g., road length, communication cost) of propagating information on road \(ij\). Parameter \(\alpha (0 \leq \alpha \leq 1)\) expresses the importance of minimizing the total length of all by-pass routes against the total propagation region.

In summary, for the ILP formulation we define constants: \(c_{ij}^m, l_{ij}^e, l_{ij}^f\); binary variables \(x_{ij}^m, y_{ij}^e, r_{ij}, a_{ij}^m, b_{ij}^m, d_{ij}^m, f_{ij}^m\); objective: (8) and constraints: (1)–(7).

We define a simpler ILP problem to reduce complexity and thus running time:

First, for each \(OD(n, m)\) calculate shortest path and set variables \(x_{ij}^m\) based on the result of the shortest path algorithm. Second, solve the following ILP problem: constants: \(c_{ij}^m, l_{ij}^e, l_{ij}^f\); binary variables: \(y_{ij}^e, r_{ij}, a_{ij}^m, b_{ij}^m, d_{ij}^m, f_{ij}^m\); objective: (8) and constraints: (2)–(7).

### 3.4 Numerical Analysis

In order to have a better understanding, the results of the SPACE ILP algorithm are presented below. The results were obtained on a nine square kilometer segment of the road network of Budapest, around the Budapest University of Technology and Economics. This segment includes three bridges over the river Danube, several main roads and downtown areas. For traffic demand we initialized a large number of routes (tens to hundreds, depending on the scenario), traversing the congested roads, considering random source-destination link pairs from the digital map. Traffic congestions were produced on a main road (middle bridge) and different side roads (from downtown area) of the road network. The bridge graph represents mean (averaged) values for traffic demands initiated from both sides of the city, considering traffic jam on one of the bridge lanes. The downtown graph represents mean values from different congested downtown roads (considering also the major roads leading to the bridge). The variance of the respective values is also represented, as a vertical bar imposed on the graphs.

Figure 3 shows the Domain of Interest (DoI) depending on the parameter \(\alpha\) (see Objective (8)). We recall that \(\alpha (0 \leq \alpha \leq 1)\) expresses the importance of minimizing the total length of all vehicle by-pass routes against the importance of minimizing the propagation region (area of dissemination). The DoI is represented as the sum of the road segment lengths included in the propagation region.

It is obvious that for both graphs the DoI increases by increasing \(\alpha\). On the other hand, the figure shows that the two types of roads represent different dynamics considering their DoI. In case when the obstacle is on the bridge, the DoI increases steeply with the increase of \(\alpha\). This means that in order to reach all roads of the maximum DoI, higher efforts must be involved for TTI dissemination. However, after a limit (\(\alpha \geq 0.6\)) the DoI is
not increasing significantly (only about 1 km). A crucial point for $\alpha$ is between 0.3–0.4, where the DoI increases significantly.

Considering congestion on downtown roads the situation is different. It can be seen, that the variance of the DoI values is higher; however, the area of DoI for downtown scenarios is only a fraction of the values of the bridge scenarios.

These observations are also validated if we consider the length of alternative (by-pass) routes in function of $\alpha$ (Figure 4). As $\alpha$ increases, the length of by-pass routes will decrease, because more and more vehicles will be able to choose the ideal by-pass routes to avoid the congestion. For the bridge scenario the length of alternative routes decreases with about 30% if we disseminate TTI by employing $\alpha = 0.4$. In case of downtown congestions, we can observe that the length of alternative routes will not decrease significantly as we increase $\alpha$, since the best by-pass routes are closer to the area of congestion. Thus, for downtown roads it is useless to disseminate the information further than the next couple of road segments (e.g. 200–300 meters), since the by-pass routes would not become shorter in any case.

Numerous analyses have been carried out that also show that the effect of $\alpha$ on the DoI and length of alternative routes is significant between 0.2 and 0.5 for most of the roads.

Until now we investigated the effect of traffic congestion on TTI dissemination considering well defined road segments (e.g. bridge) of the city. As we pointed out traffic jams can be classified in two major categories. One category is represented by traffic jams of main, crucial roads (e.g. bridge), with a large Domain of Interest and an increased length of the by-pass routes. The dissemination of TTI for such traffic incidents is extremely important, since the zone of no return of these traffic jams is also large. The second category of traffic jams is represented by downtown roads with small DoI values. Such congestions can be avoided quite easily, since there is a large number of a shorter by-pass route around them.

Now the question is how these road segments, with different relevance regarding the DoI, are situated along vehicle routes? Figures 5 and 6 present two routes from different parts of the city, where the length of DoI (considered only on this specific path) is represented in function of the link IDs along the path, where consecutively traffic jams are generated. Here we set $\alpha = 0.5$. The

![Figure 5. Effect of jammed links on dissemination along route – cross-bridge.](image)

![Figure 6. Effect of jammed links on dissemination along route – cross-town.](image)
cross-bridge route (Figure 5, length: 3261 meters) traverses the middle bridge, while the cross-town route (Figure 6, length: 2332 meters) is situated along the river. For the cross-bridge route traffic jams with large influence (large DoI) can be observed between links with IDs 113870 and 114089 (critical part), where the DoI (along the route) can reach even 1200 meters. This means that in case of a traffic jam situated along this critical part the TTI should be disseminated to a large part of the route, in order to avoid the traffic jam of the respective links with small by-pass routes. This critical part of the route contains also the bridge. For the rest of the route the congested links can be avoided easily, this is represented by small values for DoI. Some of the downtown traffic jams analyzed above (Figure 3) were taken from these road segments. In case of the cross-town route (Figure 6) the situation is almost similar, there is only one critical route part (from link ID 110879 to 114089) with larger DoI values. However, the length of the DoI for the critical links is smaller (max. 630 meters) than in case of the cross-bridge route.

As a conclusion we can affirm that different type of dissemination is necessary considering the categories of jammed road links. Some traffic jams, affecting crucial roads should be propagated to a large area (Domain of Interest), while others to a smaller one. Fortunately, as we demonstrated the usual routes are mainly constituted from links with small DoI areas, which means that in most cases the TTI dissemination of a traffic jam can be reduced significantly.

4. Performance Analysis

Simulation results were obtained using our vehicular simulation environment, called RUBeNS [2]. RUBeNS is an enhanced ns2 [14] interconnected with VISSIM [15], a microscopic, time step and behavior-based traffic simulator.

For wireless communication the standard IEEE 802.11b MAC protocol was used. We assumed that a certain amount of the vehicles are equipped with communication devices (penetration rate). We have implemented an epidemic TTI dissemination protocol with timely adaptation, and compared it with the proposed spatial adaptation algorithm. Simulations run for 3600 seconds, for a couple of thousand vehicles. Different values were set for the broadcasting interval of TTI messages (10, 20, 30). The results represent an averaged value of several simulations.

During these simulations we investigated the same types of road congestion as in the numerical analysis section. For all the scenarios the background vehicle traffic was initiated and ended in small downtown streets.

One of our goals was to investigate how the different system characteristics are affected by the variation of the area of TTI disseminations, the Domain of Interest. This is an important issue, since the number of announced traffic flows is directly related to the Domain of Interest (DoI), the area covered by disseminations.

For all the scenarios the DoI for the traffic jams was calculated by our algorithm. From the resulting DoI, different amount of road segments were taken into consideration (considering different values of $\alpha$) by the TTI dissemination protocol. The small DoI represents only the adjacent road segments of the traffic jam. The Medium DoI contains the set of most important road segments (around 30% of the overall DoI), while in the large DoI almost all the road segments from the respective DoI zone are inserted (80% of road segments).

In Figure 7, for the bridge scenario, the cumulative number of TTI messages are represented in function of the penetration rate. It can be seen, that as more and more vehicles are equipped with communication devices, the network load increases significantly. As the area of dissemination (DoI) is increased the network load is also increasing. This can be attributed to the increase in the number of roads, where the dissemination protocol will broadcast the TTI. Because of the higher number of transmissions the packet collisions will also increase, which leads to retransmissions and additional channel utilization. In the case of large DoI the number of TTI messages will overwhelm the network with a higher order of magnitude of packets.

The impact of the area covered by TTI dissemination on choosing the best alternative (by-pass) routes is presented in Figure 8. For domains of interest with small and medium size the number of vehicles choosing the best by-pass route will increase, as the penetration rate is increasing. In case of medium DoI the percentage of vehicles choosing the best by-pass route will start at 40% and will increase up to 90%, when all the vehicles are equipped with communication device. However, for large
DoI the graph shows a different tendency. It starts around 80% for a penetration rate of 5%, and drops suddenly for higher values of the penetration rate. This effect can be attributed to the increase of TTI messages and traffic congestion observed from Figure 7. Since for large DoI almost all the streets are included in the dissemination area, the vehicles will flood the entire road network, which leads to an increased volume of communication. However, for small and medium DoI only the most important road segments were selected; thus, the TTI dissemination is reduced substantially by the spatial context.

For the downtown scenario the number of road segments used in dissemination can be also reduced considering only the higher values of the \( \alpha \) parameter. Due to the characteristics of the DoI in case of downtown traffic this will lead to a substantial reduction of the dissemination area. As an effect only a few road segments will constitute the domain of interest, which leads to a remarkable decrease in the number of TTI packets. Due to lack of space the graphs with these results are omitted.

Examining the results it is important to notice the effect of spatiality on the TTI dissemination and alternative route selection. In case of low penetration rates, using a large area for TTI disseminations will increase the probability for vehicles to intercept a TTI message (e.g. carried by a vehicle to the respective place or broadcasted on some adjacent road); thus, by increasing the flooding area there will be more cars, which will take the best by-pass routes. However, as the penetration rate is increasing, this effect will result in higher network traffic and congestion, which leads to the worsening of the protocol performance. Therefore, it is advised to use DoI sets, which contain only the most important road segments (medium DoI in our case). By using the respective DoI, all the important parts of the road network will be informed by the TTI dissemination protocol; thus, the vehicles driving towards the congestion area can choose a good by-pass route.

5. Conclusion

In this paper the problem of spatial limitation of TTI message flooding in vehicular ad hoc networks has been investigated. We presented the Integer Linear Programming (ILP) formulation of the spatial context-aware forwarding problem, to calculate the areas of interest (Domain of Interest - DoI) where information about a traffic jam is to be forwarded. The outcome of our DoI calculations has been analyzed analytically, considering different congested roads and routes from a city scenario. We deduced the existence of different types of jammed links, regarding the area of DoI where TTI flooding must be employed. The distribution of such traffic jams along vehicle routes was also investigated.

The behavior of the proposed protocol was also explored through simulations. The results show clearly that higher performance is achieved by using flooding based on our DoI calculation algorithm. The DoI-aware dissemination performs better than the solutions without spatial context-awareness, in terms of channel utilization, while the travel time of vehicles remains unaffected. It was also shown that using our solution it will be more
and more beneficial as the penetration rate will increase.

Future work includes enhancements to cope with hybrid and opportunistic networking infrastructures.

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