Efficiency Analysis of Geocast Target Region Specifications for VANET Applications

Timm Jöchle, Björn Wiedersheim, Florian Schaub, and Michael Weber
Institute of Media Informatics
Ulm University
Ulm, Germany
{ timm.joechle | bjoern.wiedersheim | florian.schaub | michael.weber }@uni-ulm.de

***Abstract*—Geocast is a communication paradigm for disseminating information in a specified target region rather than based on IP addresses. Local hazard or accident warnings and warnings of approaching emergency vehicles are examples of potential use cases in vehicular ad hoc networks (VANETs). Different geocast target region specifications have been proposed in recent years. Yet, the impact of the selected geocast target region specification on communication efficiency and network overload has not been extensively studied so far. We provide a comparative analysis of different geocast target region specifications, namely circle, rectangle, polygon, and route. In our analysis we consider introduced communication overhead, as well as false positive and false negative rates for three representative VANET applications. Our simulation results show that a circular region, despite its simplicity, performs better in most scenarios than rectangular, polygon-based, or route-based regions. However, optimal radius selection has a significant impact on efficiency.**

***Index Terms*—Geocast, VANET, vehicular communication**

I. Introduction

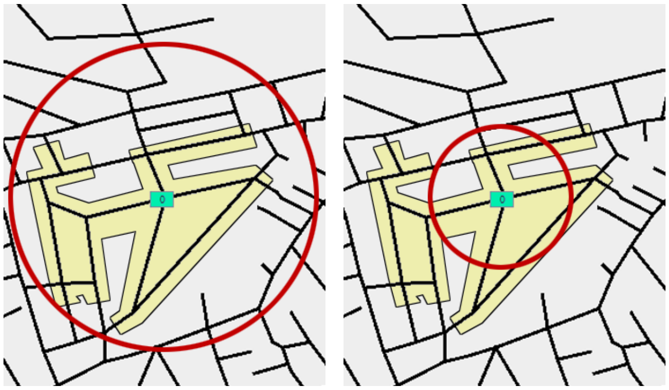
In vehicular ad hoc networks (VANETs), wireless communication between vehicles enables novel safety, traffic management, and infotainment applications [1]. Especially cooperative safety applications require that vehicles are equipped with GPS receivers to periodically inform other vehicles of their position. The availability of integrated localization technology on each node also enables new communication paradigms: position-based – or geographic – routing (*georouting*) and geographic multicast or broadcast (*geocast*) [2]. In both cases, the sender specifies a target region, sometimes called zone of relevance [3], instead of explicitly addressing a message to a number of specific receivers. Several standardization organizations have specified message formats for inter-vehicular communication. The DENM standard [4] specifies geocast messages with a destination area and a relevance area. To avoid confusion, we consistently use *target region* and *interest region* in this paper.

Typically proposed applications require that a message is disseminated in a certain area extending beyond the sender's transmission range. Examples are warning vehicles about construction zones or accidents on the road ahead [5], [6] or about approaching emergency vehicles [7]. If the sender is located outside the target region, the message is routed by intermediary hops based on their geographic position (*georouting*). Vehicles inside the target region process the message and disseminate it further to other vehicles in the region (*geocast*). Thus, a vehicle's position determines if it is a recipient of a message or not. This approach is beneficial in VANETs, because most warning messages pertain to a certain area rather than individual vehicles. Moreover, addresses of potential receivers are likely unknown to the sender due to multi-hop propagation and highly dynamic network topologies.

Extensive work exists on the topic of efficient geographic routing to the target region [8]–[12], as well as efficient message dissemination protocols for geocast inside the target region [13]–[15]. Karagiannis et al. [1] and Lin et al. [16] provide extensive overviews on position-based routing and broadcast protocols. In the target region, naïve flooding would cause broadcast storms [17] and quickly lead to network congestion, especially in dense traffic. Therefore, adaptive and probabilistic forwarding schemes have been developed that efficiently propagate the message to all vehicles inside the target region, while avoiding unnecessary or redundant retransmissions. Maihöfer [18] analyzes the efficiency of multiple geocast protocols in simulations. Schoch et al. [2] give an overview of potential applications that could utilize geocast.

However, these protocols, as well as Maihöfer's analysis, operate under the assumption that all vehicles in the specified target region are intended recipients of the message. Yet, the geometric shape of the target region specified in a geocast message is only an approximation of the actual *interest region*. We define the interest region as that region that includes all intended recipients of a message, or worded differently, the region in which all vehicles are interested in the message contents. The specified target region may not fully correspond to the interest region, because the target region specification must adhere to the region geometries supported by the message format. In some cases it is hard to determine the interest region, so assumptions have to be made. This of course can lead to non-optimal target region specifications. As vehicles may enter or leave the interest region, the number of intended recipients may also change over time. To reach new vehicles that just entered the interest region, the messages will be sent periodically, as long as the reason for sending out the messages exists. In the example in Figure 1, the target region for an accident warning is specified as a circle (longitude, latitude, radius), but the interest region includes all vehicles driving towards the accident side.

In IEEE Vehicular Networking Conference (VNC 2012), Seoul, November 2012
Author version. Definitive version at ieeeexplore.ieee.org



(a) Target region too wide. (b) Target region too narrow.

Fig. 1. Relation between geocast target region and actual interest region.

In this paper, we investigate the impact of different target region specifications on network overload. If the specified target region is larger than the interest region (Fig. 1a), many vehicles that have no use of the warning message have to process and forward it anyway. If the target region is too narrow (Fig. 1b), some interested vehicles will not receive the message in time to divert the route or warn the driver. The interest region can be approximated more precisely by more complex target region specifications, but those require additional information in the message header to describe the target region shape. They also increase the processing complexity to determine if a vehicle is inside the target region. Therefore, an optimal target region specification would match the interest region as closely as possible to reach all interested vehicles without causing unnecessary network congestion, while at the same time keeping target region specification simple, in order to keep per message overhead low.

So far, proposed target region specifications are often optimized for specific applications or application categories. Circular or rectangular regions are often proposed for incident warning applications [4]; polygon or route-based regions aim to better align with the road network to disseminate warnings only relevant to certain street segments, such as traffic congestion or emergency vehicle warnings.

Considering that the chosen geocast target region can have a non-negligible influence on network load, it is essential to understand the impact of differing target regions on network communication. In this work, we analyze the effect of different geocast target region specifications on the efficiency of three representative VANET applications. Our simulation results give clear indications on the versatility of different target regions and can inform standardization and deployment decisions.

In Section II we give a more detailed introduction of geocast and define four commonly proposed target region specifications. Our study design is described in Section III, including selected VANET applications, employed metrics, and simulation setup. We present and discuss our simulation results in Sections IV and V. Section VI concludes the paper.

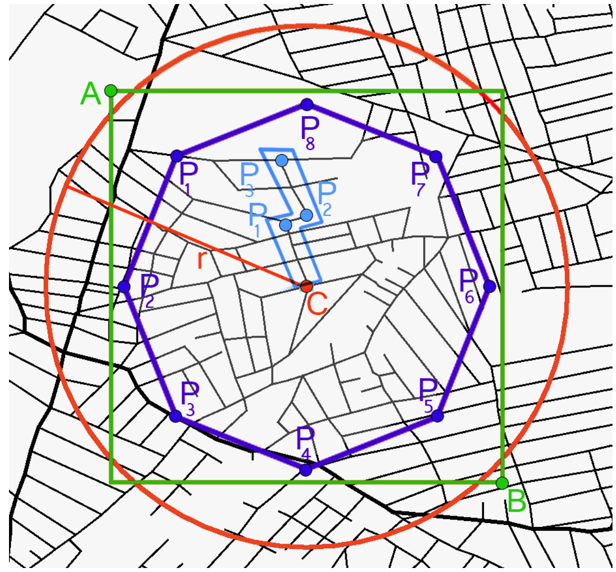


Fig. 2. Specification of the target regions.

II. Geocast

Geocast was originally proposed by Navas & Imielinski [19] as GPS-multicast, with the idea to extend DNS to support geographic addresses [20]. Geocast aims to disseminate a message within a region defined by geographic coordinates. The message is first forwarded via unicast from the sender to the geographic region in which it is then broadcasted to all vehicles inside that target region. To avoid broadcast storms caused by naïve flooding, probabilistic dissemination protocols are typically employed [2] to minimize the message traffic in the target region.

A. Target region specification

Circle, rectangle, polygon, and route are the dominant region specifications. Different sizes and variations of how to define the respective shapes have been proposed by related work. In the following, we provide common definitions for these target regions in order to subsequently analyze their communication efficiency. Figure 2 provides an overview of the different shapes.

1) Circle: The GeoNet[1] geocast specification supports only circular target regions [21]. The geocast message is disseminated in a circular region defined by a center point p, which is defined as a geographic coordinate consisting of longitude and latitude and a radius r. Thus, this region specification can be defined quite efficiently, but potentially also addresses a lot of vehicles that are not interested in the message, because message content is not relevant for them. Assuming a fixed center point, the radius r solely determines the region's extent and coverage. Therefore, we will assess circular regions with different r in our analysis.

[1]GeoNet project website: http://www.geonet-project.eu/

2) Rectangle: A rectangular geocast region can be specified with two points [22]. The points p_1 and p_2 define one of the rectangle's diagonal, which is sufficient to reconstruct the complete rectangle. Each point consists of longitude and latitude. Due to limited precision, many potentially non-interested vehicles are still addressed in incident warning applications. However, a rectangular region specification can be efficient if the interest region is also rectangular [23], e.g., warning oncoming vehicles on a relatively straight highway stretch. Rectangular region specifications can be extended with an additional degree of freedom by adding an angle α in order to rotate the region. Such rotation requires the definition of a rotation point. However, the rotation point can be derived from the rectangular region, for instance, using one of the corner points or the rectangle's centroid. The efficiency of the rectangular region can be improved by dynamically adapting the length, width, and angle of the region to the direction, traffic density, and infrastructure. To enhance comparability with the other shapes, we focus on quadratic rectangles in our analysis and vary the square length l in our simulations.

3) Polygon: The polygon region is defined by a list of edge points $(p_1, \ldots, p_n)$. Theoretically, a polygon allows a very precise region specification, which exactly matches an application's interest region. However, encoding multiple points, each consisting of latitude and longitude, incurs considerable overhead. Therefore, an upper bound for the number of edge points (n) is required in order to find a tradeoff between specification precision and overhead. The number of edge points can also be dynamically adapted up to this limit according to the interest region. Polygon regions are ideal for applications that require a very precise dissemination area and can bear the overhead.

4) Route: The route-based region specification aims to provide precision similar to polygon regions while incurring less overhead. Instead of describing a polygon's complete perimeter with edge points, the route-based region marks a number of points $(p_1, \ldots, p_m)$ along a route. Additionally, a distance d is specified that defines a corridor around the abstracted route in which messages are disseminated [7]. While the route-based region needs considerably fewer points than the polygon region, it requires the sending vehicle to have a known route in order to derive the optimal number of points to represent the route. The route-based region can be seen as a specialized polygon that is especially suited for route-based applications, e.g., an emergency vehicle warning other traffic participants of its approach [7].

Both, polygon and route specification benefit from access to map data at the sending vehicle, because the target region can be better aligned with the road network.

III. Study setup

Our goal is to analyze the efficiency of these different geocast region specifications in different application scenarios in order to determine their suitability, versatility, and efficiency. Our analysis is based on a simulation study. In the following, we describe the chosen applications scenarios as well as our methodology and study setup. As the geocast target area only has limited effect on motorways and straight highways, we choose an inner city scenario as use case for our simulations.

A. Representative applications

For our simulation scenarios, we chose applications from three different categories defined by Schoch et. al. [2]. We outline the rationale of each application and define a realistic interest region. We also formulate a hypothesis on which region specification would likely perform best in the given inner city scenario, based on a comparison of overlap between target and interest region.

1) Local danger warning: As an *active safety* application, we chose a *post-crash or breakdown warning* application. One broken down or crashed vehicle with a fixed position generates warning messages in order to inform approaching vehicles about the potential road hazard. A crash or breakdown on one lane may as well influence the traffic situation on other lanes and even oncoming traffic, due to scattered vehicle parts. The warning is relevant to any vehicle approaching the sending vehicle independently of its driving direction. Therefore, we choose a circular area with radius 700 m as the interest region, giving the drivers enough time to react on the warning or to recalculate their route. Consequently, we expect the circular target region specification to perform best in this case.

2) Emergency vehicle warning: The second application is the *approaching emergency vehicle warning* from the category *public service*. An emergency vehicle is broadcasting the next segment of its route to provide drivers with sufficient time and information to properly give way to the emergency vehicle. A circular area with a radius of 100 m roughly corresponds to the area in which the emergency vehicle's sirens are audible. The part of the interest region surrounding the emergency vehicle's next route segments for a distance of about 1000 m contains vehicles that will likely encounter the emergency vehicle. The polygon or route-based target region specifications are expected to perform best in this application, as they can closely match the emergency vehicle's route.

3) Ride sharing request: The *ride sharing* application stems from the *improved driving* category. To reduce CO_2 emissions of road traffic, recent publications propose improving the utilization of available seat capacity by dynamic ride sharing applications [24]. VANETs could also be used to coordinate hitchhikers and ride sharers without the need of centralized services. A person with a smartphone sends out ride sharing requests. In this case, the interest region is defined by the area in which the ride sharer can be picked up. Therefore, the interest region corresponds to an irregular polygon. A polygon-based target region can optimally describe the interest region.

B. Methodology

For each of these applications, we set up a simulation scenario in which one node is periodically generating messages and transmitting them to the surrounding nodes. The messages contain application-specific information (i.e., a road hazard warning or a ride sharing request) and a definition of a geocast region. For all our applications, we defined a specific interest region, containing all vehicles that should receive the message. We simulate each application with the different target region specifications defined in Section II. The employed geocast target region influences message dissemination. Nodes receiving the message outside the specified area are simply ignoring the message, while nodes inside the area are processing and forwarding it to other nodes in their neighborhood. We use simple flooding as a baseline approach for message dissemination, since we focus on analyzing the effects of different region specifications and not on advanced dissemination protocols.

C. Metrics definition

We split vehicles into four groups, depending on their location inside or outside the interest region and whether they have received at least one message from the generator node.

- *True positives.* Nodes inside the interest region that received a message.
- *False negatives.* Nodes inside the interest region that did not receive a message.
- *False positives.* Nodes outside the interest region that received a message.
- *True negatives.* Nodes outside the interest region that did not receive a message.

Like in other decision based scenarios, the goal is to minimize false positives and false negatives. As it is usually impossible to avoid them completely, we are also interested in the ratio between false positives and negatives. For safety applications, like local danger warnings, it is most important to minimize false negatives even if that causes a higher rate of false positives. Vehicles inside the interest region have a higher risk of being involved in an accident and, therefore, have to be warned, even if other vehicles also receive the warning without benefiting from it. For non-safety applications, on the other hand, false positives should be reduced in order to decrease the overall network load caused by the application.

We define the following metrics to evaluate our simulation results for the different geocast regions. Let V_i be the set of vehicles inside an interest region, V_r the set of vehicles that received a message, M_i and M_o the number of messages received inside/outside the interest region, and D the data size of the region specification per message.

- Accuracy of message transport (true positives normalized by the number of vehicles inside the interest region)

$$M_{ac} = \frac{|V_i \cap V_r|}{|V_i|} \tag{1}$$

- False positives and false negatives normalized by the total number of vehicles

$$M_{fp} = \frac{|V_r \setminus V_i|}{|V|} \tag{2}$$

$$M_{fn} = \frac{|V_i \setminus V_r|}{|V|} \tag{3}$$

- Amount of network overhead inside and outside interest region caused by the region specification

$$M_{ov} = (M_i + M_o) \cdot D \tag{4}$$

The data size D depends on the number of parameters required for the region specification, for instance, the number of points. We defined a usage of 8 bytes per point p_i (4 bytes each for a point's longitude and latitude). For the circle radius r and route distance d we also assume 4 bytes. The resulting data sizes for the different region specifications are: circle ($D_{circ} = 12\,\text{bytes}$), rectangle ($D_{rect} = 16\,\text{bytes}$), polygon ($D_{poly} = n \cdot 8\,\text{bytes}$), route ($D_{route} = m \cdot 8 + 4\,\text{bytes}$).

D. Simulation setup

Our simulations are based on the JiST/Swans[2] simulation environment. Using the STRAW OD-mobility model [25], the vehicles randomly choose a destination and calculate a corresponding route that they follow until the destination is reached. We chose an inner city road map of Boston of 4000 m x 4000 m, because all our applications support urban traffic scenarios. We varied the amount of vehicles driving on our map from 50 to 250, ranging from low traffic usually occurring during night times and higher traffic in the afternoon. We limited the amount of simulated vehicles to 250, because for higher vehicle numbers congestions start occurring, leading to an unbalanced traffic density throughout the map, which causes higher variations in the simulation results.

To reflect the limited range of wireless connections in inner cities, we set the transmission range to 300 meters. For network communication, we simulated 802.11-based network connections, using freespace pathloss without fading. Each simulation run took 1000 seconds of simulation time and 20 simulation runs were averaged to calculate one plot in the diagrams. The map was generated using data from the US Census Bureau TIGER database.[3]

For demonstration and verification purposes, we enhanced the existing simulation visualization. During the simulation run, the interest region (yellow) and target region (blue) are displayed in different colors. Additionally, vehicles change colors when entering the interest region and when they receive at least one warning message.

The clear visualization facilitated effective monitoring and supported the detection and elimination of inconsistencies in our simulation setup.

IV. Results

In the following, we evaluate the simulated results for each application by means of the proposed metrics.

A. Emergency vehicle warning

In order to compare performance of the different target region specifications, we first had to select reasonable parameters for the circle and rectangle specifications. After initial

[2]http://vanet.info/node/11.html

[3]U.S. Census bureau maps and cartographic resources. http://www.census.gov/geo/www/maps

Fig. 3. Interest region and all target regions for emergency vehicle warning.

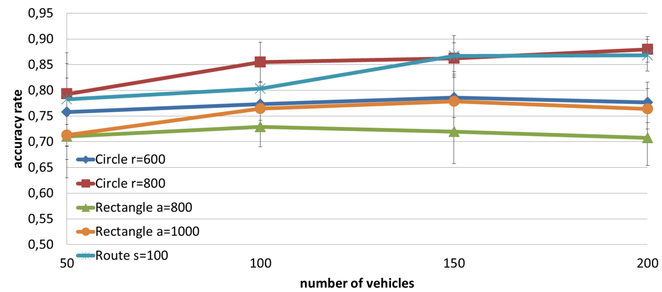


Fig. 4. Accuracy M_{ac} of message transport for emergency vehicle warning.

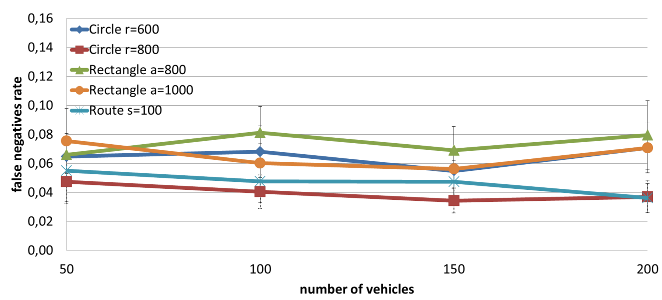


Fig. 5. False negative rates M_{fn} for emergency vehicle warning.

simulations, the polygon region was removed from consideration, because it basically emulates the route region but with significantly higher overhead (D). For the circle region we evaluated different radii (400-1,400 m) with 50 vehicles. We selected two radii (600 m, 800 m) for further comparison due to high M_{ac}. Larger circle sizes are unnecessary, because a circular region with radius 800 m already includes the whole interest region in most cases, because the emergency vehicle's route (length 1000 m) is typically not fully linear in urban scenarios. We performed an analogous evaluation of rectangle regions of different sizes and selected rectangle regions with 800 m and 1000 m length and width for further comparison. Due to space limitation, we omit detailed results of the initial parameter selection.

After selecting suitable parameters, we evaluated the performance of five different target regions for the emergency vehicle warning application with varying traffic density. Figure 3 shows the interest region and the evaluated target regions. Note, that the interest region was dynamically chosen per simulation run as the emergency vehicle did not have a fixed position or destination.

Figure 4 shows the accuracy of message transport results (M_{ac}) for the different regions. Furthermore the standard deviations of the simulations for each plot is shown in this and every following figure as error bars. Accuracy of the route region and the circle region with 800 m radius is quite high. However, the route region can only match the accuracy of the circle region for higher traffic density. This stronger dependency on traffic density is likely due to the relatively narrow geocast target area around the route, which cannot guarantee successful message dissemination without sufficient vehicles.

Due to the safety critical nature of the application, warnings should reach as many vehicles inside the interest region as possible, thus, a low false negative rate (M_{fn}) should be aspired. In Figure 5 the lowest M_{fn} are achieved by the route region and the circle region with 800 m radius.

Figure 6 shows the generated overhead due to region specification for each region. Although the route region specification incurs the highest data size with a dynamic number of points, it generates overall less overhead than the circle and rectangle regions, because of its exact precision.

Summing up the results of the emergency vehicle warning application, the route region performs as well as expected by exhibiting high accuracy, low overhead, and very few false positives. However, the circle region with 800 m radius performs also quite well and is more robust against low traffic density than the route region. The higher overhead is likely acceptable for a safety critical application.

B. Local danger warning

For the local danger warning application, we proceeded similar to the emergency vehicle application and first selected suitable parameters for the different regions. The route region was not considered, as defining a route makes no sense in this

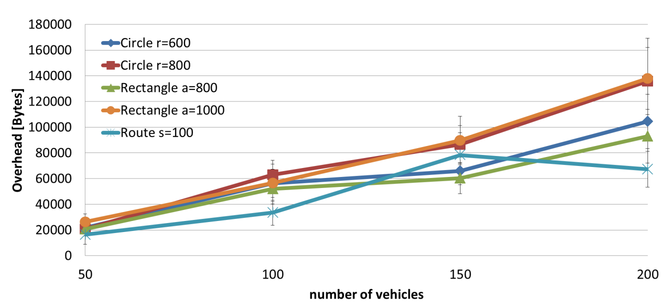


Fig. 6. Data overhead M_{ov} for emergency vehicle warning.

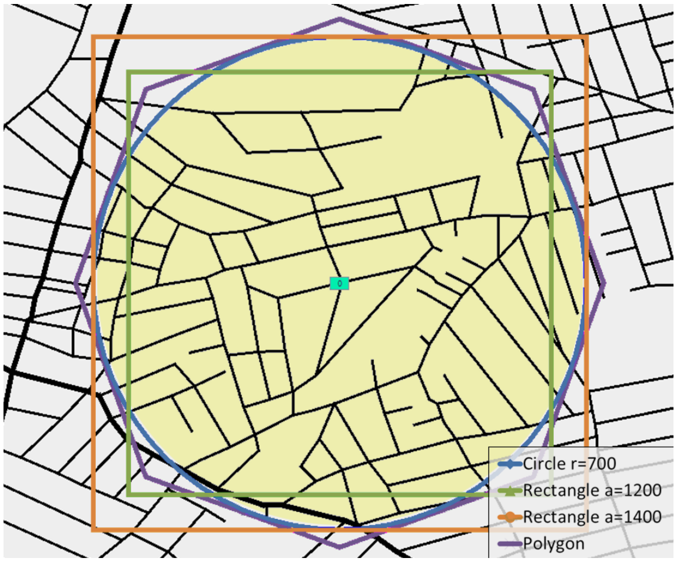


Fig. 7. Interest region and all target regions for local danger warning.

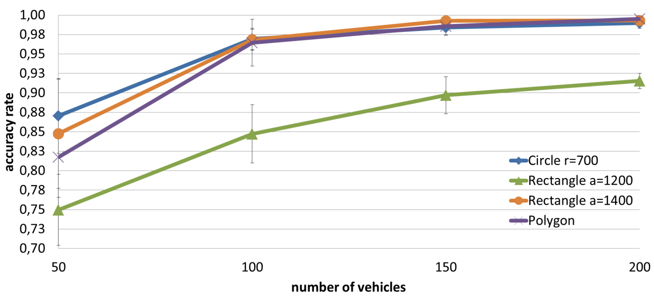


Fig. 8. Accuracy M_{ac} of message transport for local danger warning.

scenario. The circle region was selected with radius 700 m to match the interest region. We selected two rectangular regions with 1,200 m and 1,400 m length and width. The first one includes the complete interest region, while the latter showed significantly less inaccuracy. For the polygon region, the interest region was approximated by an octagonal shape. Interest region and the four different target regions are shown in Figure 7.

Figure 8 shows the accuracy results for varying traffic density, and Figure 9 shows false negative rates. Not surprisingly, the circle region performed best with a high accuracy and very low M_{fn}, because it matches the interest region. Conversely, the smaller rectangle region does not completely match the interest region and reaches a lower accuracy and a higher M_{fn} value. In addition, the overhead is also very low for the circle region (see Fig. 10), because it covers a smaller area than the other target regions, and therefore less messages need to be forwarded.

C. Ride sharing request

For the ride sharing application, we chose the circle and rectangle region parameters such that one region variant completely contains the interest region (circle radius 1,250 m, rectangle length 2,000 m) and another variant that does not cover the interest region completely but likely produces less false positives (circle radius 1,000 m, rectangle length 1,500 m). We further defined a polygon region that matches the interest region. Definition of a route would not make sense, as it would require too many points to cover the interest region. Figure 11 shows the interest region and selected target regions.

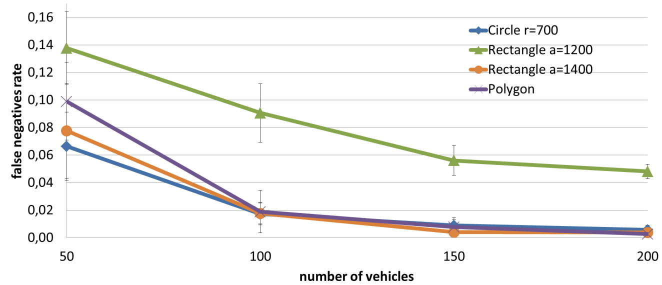


Fig. 9. False negative rates M_{fn} for local danger warning.

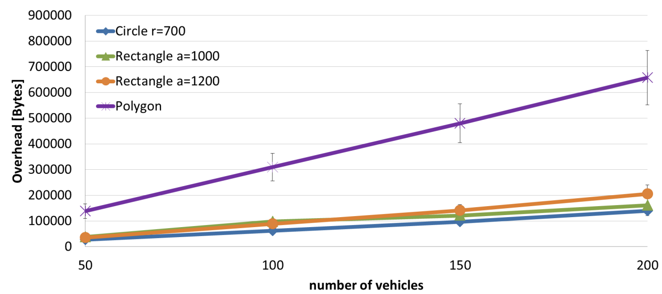


Fig. 10. Data overhead M_{ov} for local danger warning.

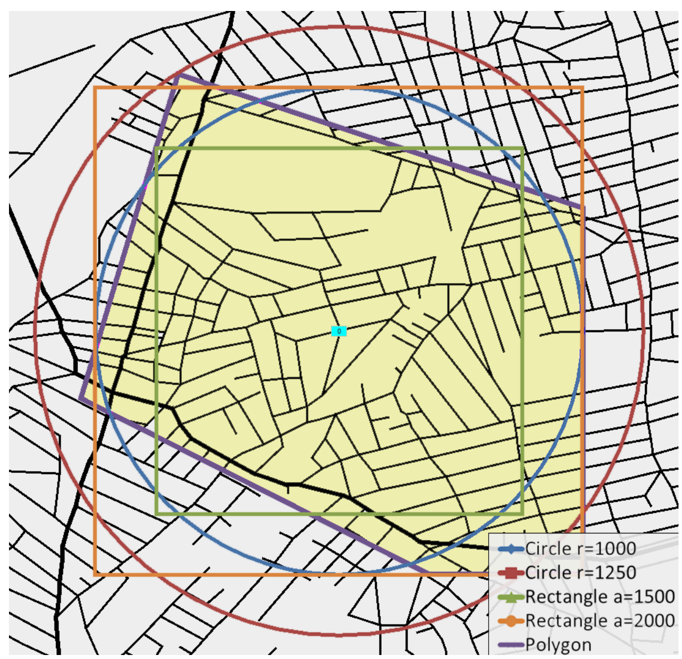


Fig. 11. Interest region and all target regions for ride sharing request.

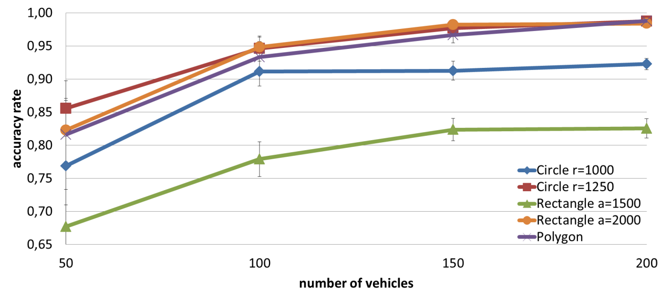


Fig. 12. Accuracy M_{ac} of message transport for ride sharing request.

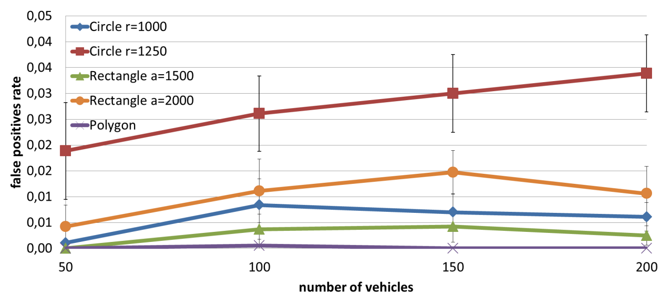


Fig. 13. False positive rates M_{fp} for ride sharing request.

Our results show that the larger circle and rectangle regions, as well as the polygon region achieve very high accuracy (see Fig. 12). Nevertheless, the circle region with 1,000 m radius also reaches above 90% accuracy.

The overhead M_{ov} of the polygon region (see Fig. 14) is very high compared to the other regions. However, the false positive rate of the polygon region (see Fig. 13) is very low as desired for a non-safety application. Yet, the smaller circle region also provides a low false positives value.

Considering the high overhead of the polygon region, the smaller circle region is most suitable for this scenario. It provides both decent accuracy and low overhead while maintaining a low false positive rate.

V. Discussion

As we have demonstrated, the results of our simulations differ according to the type of specified target regions, the kind of application and the vehicle density. In all three application scenarios, a different specification shape for the target region performed best. However, in each case a circular target region also reached an acceptable accuracy rate with a particularly low network overhead, despite a rather generous data size assumption for the radius parameter (4 bytes). Overall, efficiency of circular geocast regions seems to be better than their reputation, even for applications that would intuitively benefit from a more tailored region specification. Thus, if an OBU's network stack should only support one kind of geocast region specification, the circular region provides the best overall results independent of specific applications.

Yet, the efficiency of the geocast message dissemination strongly depends on the selection of a fitting radius r. If r is chosen too large, the false positive rate increases quickly, choosing r too narrow results in more false negatives. The accuracy of message dissemination also depends on vehicle density. The higher the vehicle density, the more precisely the target region must match the interest region in order to maintain high accuracy by reducing false positives. In cases of low vehicle density, on the other hand, the message may not be disseminated in the whole target region, i.e., it might not reach vehicles at the region's border. In that case, a significant number of vehicles might miss the message and the number of false negatives rises. Thus, a higher density will increase the reliability of the system, as long as the network channels are not congested.

Our results are based on simulations that necessarily simplify real world conditions to some extend. Our simulation environment does not take interference from buildings into account, which would heavily influence the communication range between nearby roads in urban areas. As discussed in Section III-D, we compensated this by reducing the transmission range accordingly. In our scenarios, we only considered one vehicle generating new messages at a time. Therefore, our applications did not have to compete with other applications about limited network bandwidth, as would be the case in the real world. Nevertheless, the isolated simulation of one application serves well to analyze the effects of different region specifications, which might be lost in more realistic scenarios. Moreover, the 802.11p standard foresees separate channels for safety applications, reducing competition for bandwidth.

In our simulations, the messages inside the target regions were flooded, meaning that each node inside the target region rebroadcasts all messages that it receives, which results in high network load for high vehicle densities. More sophisticated approaches exist that cope with this problem by reducing the total number of sent messages, while preserving the number of vehicles that receive the information. In our use cases, those algorithms could further increase the efficiency of message dissemination and reduce network load.

In our work, we focused on an inner city scenario, because the geocast region would likely not have much influence on other road types, such as motorways or long country roads without intersecting streets. In such environments, dissemination to parallel roads becomes less of an issue, because

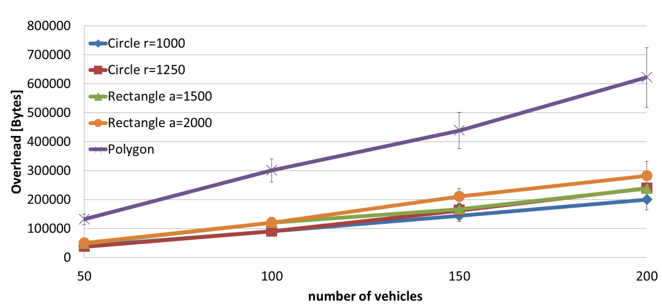


Fig. 14. Data overhead M_{ov} for ride sharing request.

roads are far apart. Therefore, the dissemination distance on the current road, would be the most dominant parameter. As a result, the circular region would likely also perform best for two reasons. It requires the lowest overhead per message and dissemination would be limited to the road anyway, because of a lack of forwarding vehicles off the road.

Of course, real message formats are much more complex than those assumed in our simulation. Additional message parts like signatures and certificates may outweigh the amount of bytes needed for the geocast addressing. Therefore the overhead in our figures does not reflect the total message overhead. But it is nevertheless important to reduce overall message size by using compact geocast region specifications, as shorter messages reduce the probability of packet collisions and the need to split up information on several messages due to a fixed maximum message size.

VI. Conclusion

Our simulation results show that circular region specifications perform remarkably well even for VANET applications with more complex interest regions, such as emergency vehicle warning or ride sharing. The small amount of information required per message for specification of a circle region (longitude, latitude, radius) trumps the closer match to the interest region offered by polygon and route-based regions, because those regions require significantly more information for target region specification. Thus, circular geocast region specification seems like an appropriate choice for a multi-purpose geocast definition. This could have influences on ongoing and future standardization processes of VANET message formats. However, our results also show that the optimal selection of the circle's radius is highly scenario dependent and requires careful calibration to prevent communication overhead. A future research challenge is the development of mechanisms and strategies that sending vehicles can employ to dynamically determine optimal parameter selection.

Acknowledgments

The authors would like to thank Stefan Dietzel for helpful comments on an earlier draft of this paper.

References

[1] G. Karagiannis, O. Altintas, E. Ekici, G. Heijenk, B. Jarupan, K. Lin, and T. Weil, "Vehicular Networking: A Survey and Tutorial on Requirements, Architectures, Challenges, Standards and Solutions," *IEEE Communications Surveys & Tutorials*, vol. 13, no. 99, pp. 1–33, 2011.

[2] E. Schoch, F. Kargl, and M. Weber, "Communication patterns in VANETs," *IEEE Comm. Mag.*, vol. 46, no. 11, pp. 119–125, Nov. 2008.

[3] F. Li and Y. Wang, "Routing in vehicular ad hoc networks: A survey," *IEEE Vehicular Technology Magazine*, vol. 2, no. 2, pp. 12 –22, 2007.

[4] "ETSI TS 102 637-3 V1.1.1, Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service," European Telecommunications Standards Institute (ETSI), Tech. Rep., September 2010.

[5] A. Benslimane, "Optimized dissemination of alarm messages in vehicular ad-hoc networks (VANET)," in *Intl. Conf. on High Speed Networks and Multimedia Communications (HSNMC'04)*. Springer, 2004.

[6] Q. Yu and G. Heijenk, "Abiding geocast for warning message dissemination in vehicular ad hoc networks," in *IEEE ICC Workshops*, 2008.

[7] A. Buchenscheit, F. Schaub, F. Kargl, and M. Weber, "A VANET-based Emergency Vehicle Warning System," in *IEEE Vehicular Networking conference (VNC 2009)*. IEEE, 2009.

[8] B. Karp and H. T. Kung, "GPSR: greedy perimeter stateless routing for wireless networks," in *Intl. conf. on Mobile computing and networking (Mobicom '00)*. ACM, 2000.

[9] C. Maihöfer, R. Eberhardt, and E. Schoch, "CGGC: Cached greedy geocast," in *Intl. Conf. on Wired/Wireless Internet Communications (WWIC'04)*. Springer, 2004.

[10] A. Wahid, H. Yoo, and D. Kim, "Unicast geographic routing protocols for inter-vehicle communications: a survey," in *5th ACM workshop on Performance monitoring and measurement of heterogeneous wireless and wired networks (PM2HW2N '10)*. ACM, 2010.

[11] H. Ghafoor and K. Aziz, "Position-based and geocast routing protocols in VANETs," in *7th Intl. Conf. on Emerging Technologies (ICET'11)*, 2011.

[12] S. Das and D. K. lobiyal, "Analysis of next hop selection for geocasting in VANET," in *Intl. Conf. on Computer Science, Engineering and Information Technology (CCSEIT'11)*. Springer, 2011.

[13] C. Maihöfer, T. Leinmüller, and E. Schoch, "Abiding geocast: time–stable geocast for ad hoc networks," in *2nd ACM international workshop on Vehicular ad hoc networks (VANET'05)*. ACM, 2005.

[14] B. Bako, F. Kargl, E. Schoch, and M. Weber, "Advanced adaptive gossiping using 2-hop neighborhood information," in *IEEE Global Telecommunications Conference (GLOBECOM'08)*, 2008.

[15] Y.-S. Chen, Y.-W. Lin, and S.-L. Lee, "A mobicast routing protocol in vehicular ad-hoc networks," *Mob. Netw. Appl.*, vol. 15, no. 1, pp. 20–35, 2010.

[16] Y.-W. Lin, Y.-S. Chen, and S.-L. Lee, "Routing protocols in vehicular ad hoc networks: A survey and future perspectives," *Journal of Information Science and Engineering*, vol. 26, pp. 913–932, 2010.

[17] S.-Y. Ni, Y.-C. Tseng, Y.-S. Chen, and J.-P. Sheu, "The broadcast storm problem in a mobile ad hoc network," in *ACM/IEEE Intl. Conf. on Mobile computing and networking (MobiCom '99)*. ACM, 1999.

[18] C. Maihöfer, "A survey of geocast routing protocols," *IEEE Communications Surveys & Tutorials*, vol. 6, no. 2, pp. 32 –42, 2004.

[19] J. C. Navas and T. Imielinski, "Geocast - geographic addressing and routing," in *ACM/IEEE Intl. Conf. on Mobile computing and networking (MobiCom '97)*. ACM, 1997.

[20] T. Fioreze and G. Heijenk, "Extending the domain name system (DNS) to provide geographical addressing towards vehicular ad-hoc networks (VANETs)," in *IEEE Vehicular Networking Conference (VNC'11)*, 2011.

[21] A. Kovacs, "D2.2 final geonet specification," GeoNet project, Tech. Rep., 2010. [Online]. Available: http://www.geonet-project.eu/

[22] A. Festag, P. Papadimitratos, and T. Tielert, "Design and performance of secure geocast for vehicular communication," *IEEE Transactions on Vehicular Technology*, vol. 59, no. 5, pp. 2456 –2471, 2010.

[23] P. Yao, E. Krohne, and T. Camp, "Performance comparison of geocast routing protocols for a MANET," in *Intl. Conf. on Computer Communications and Networks (ICCCN'04)*, 2004.

[24] N. Agatz, A. Erera, M. Savelsbergh, and X. Wang, "Sustainable passenger transportation: Dynamic ride-sharing," Erasmus Research Institute of Management (ERIM), Erasmus Uni., Rotterdam, Tech. Rep., 2010.

[25] D. R. Choffnes and F. E. Bustamante, "An integrated mobility and traffic model for vehicular wireless networks," in *2nd ACM international workshop on Vehicular ad hoc networks (VANET'05)*. ACM, 2005.