GEMV^2: Geometry-based Efficient propagation Model for V2V communication

http://vehicle2x.net

User Manual, Version 1.1

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Contents

1 Introduction

This user manual describes the MATLAB implementation of GEMV^2, a geometry-based, efficient propagation model for vehicle-to-vehicle (V2V) communication [1]. The main features of GEMV^2 are:

- Uses outlines of vehicles, buildings, and foliage to distinguish the following three types of links: line of sight (LOS), non-LOS due to vehicles, and non-LOS due to static objects
- Deterministically calculates large-scale signal variations (path-loss and shadowing)
- Calculates the small-scale signal variations using the number and size of objects around the communicating vehicles
- Validated against measurements in urban, suburban, highway, and open space environments
- Imports vehicular mobility from SUMO; uses floating car data format to generate vehicle outlines
- Imports outlines of buildings and foliage from OpenStreetMap
- Easily extendable to import vehicular mobility and object outlines from other data sources
- Exports the visualization of vehicular communication to KML format (for use with Google Earth or NASA World Wind)
- Implemented in MATLAB; free of charge and openly distributed

This user manual describes how to install and run GEMV^2, what type of output it generates, and gives a high-level overview of GEMV^2 code. For a detailed description of GEMV^2 from a research standpoint, please refer to the following paper:

Mate Boban, João Barros, and Ozan K. Tonguz: "Geometry-Based Vehicle-to-Vehicle Channel Modeling for Large-Scale Simulation," IEEE Transactions on Vehicular Technology, 2014, doi:10.1109/TVT.2014.2317803 [PDF][BIB]

MATLAB implementation of GEMV^2 can be used as a standalone tool for analyzing V2V communication in terms of key communications and networking performance metrics: received power, packet delivery rate, interference levels, neighborhood size, etc.). GEMV^2 can also be used as a propagation model for discrete-time network simulators (e.g., NS-3, JiST/SWANS/STRAW), either offline (i.e., by providing the output from the MATLAB implementation to the simulator) or online (by re-implementing GEMV^2 in the simulator).

2 Getting Started

2.1 Installation

Installation of GEMV^2 is quite simple: download the `.zip` file containing GEMV^2, unzip to a directory, and you're ready to go! Since GEMV^2 code is organized in package folders[1], there is no need to add any directories to MATLAB path. Furthermore, care has been taken so that GEMV^2 depends on as few MATLAB toolboxes as possible. That said, mapping, statistics and machine learning toolbox can speed up the simulation considerably, since the "backup" functions, used in case these toolboxes are unavailable, are far slower. GEMV^2 should work on any platform running recent version of MATLAB. However, because it uses package folders, it will not work with MATLAB R2007b and older without some modifications. It was tested with MATLAB R2011a, R2011b, R2012b, and R2013a under Mac OS X and Windows.

2.2 Running the simulation

To run the simulation, go to GEMV^2 root directory and type `runSimulation` in MATLAB command window. This will kick off the simulation by loading the script `runSimulation.m`, which in turn loads `simSettings.m`, the script that contains the default settings, including the source files for vehicle, building, and foliage outlines, propagation-related parameters, visualization options, etc.

2.3 Simulation output

After the simulation is finished, relevant variables related to received power, small- and large-scale variations, link types, etc., are saved in two formats:

- MATLAB `.mat` file (suitable for easy manipulation in MATLAB);
- comma-separated values (`.csv` files), with each variable saved in a different file (suitable for analyzing the results outside MATLAB).

Output files can be found in `outputSim` directory, located in the main GEMV^2 directory. The file names are appended with current date; note that if you do not copy/rename the output files and if there were simulation runs previously that day, the output from those runs will be overwritten.

[1] For details, please refer to `http://www.mathworks.com/help/matlab/matlab_oop/scoping-classes-with-packages.html`

2.3.1 Visualizing the output of GEMV^2

GEMV^2 generates the V2V simulation output in Keyhole Markup Language (KML) format. To visualize the result, you can use Google Earth[2] or NASA World Wind [4], though any tool for displaying three-dimensional virtual globe[3] can be used, provided that it supports KML format.

Figure 1 shows the Google Earth visualization in terms of power, whereas Fig. 2 shows the visualization of neighborhood size (defined as the number of vehicles that the ego vehicle can communicate with directly/without multi-hop communication). If the simulation is composed of multiple time-steps, the output is an animation of all time-steps (a number of sample videos is available at `http://vehicle2x.net/videos`). The visualization enables easier understanding of propagation characteristics in vehicular communication. More details are available in the demo paper on visualization [5]. Note: if the output is large (large being a few hundred thousand communication pairs in total or, alternatively, a few hundred megabytes), the following can occur:

- generating the `.kml` file can take a long time;
- opening the Google Earth output can be cumbersome and could even lead to Google Earth throwing an "out of memory" error (e.g., for `.kml` files larger than a few hundred megabytes).

Therefore, make sure to turn the visualization off in such cases.

2.4 GEMV^2 function dependencies

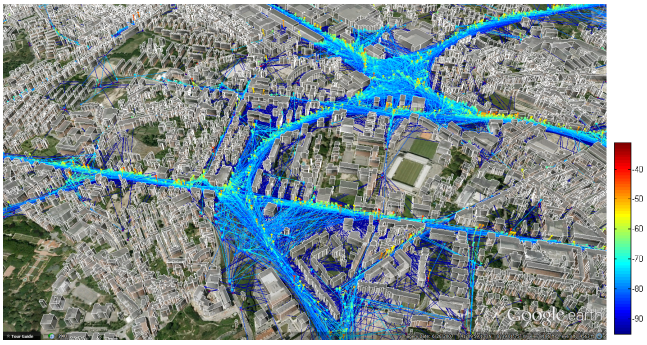
Figure 3 shows GEMV^2 function dependencies. The functions have been organized in package folders based on their functionality (e.g., functions for loading data are in `+loadFunctions` directory, functions for plotting are in `+plotFunctions`, etc.). Each function shown in Fig. 3 has been thoroughly commented; therefore, for a detailed description, open the containing `.m` file.

2.4.1 External function dependencies

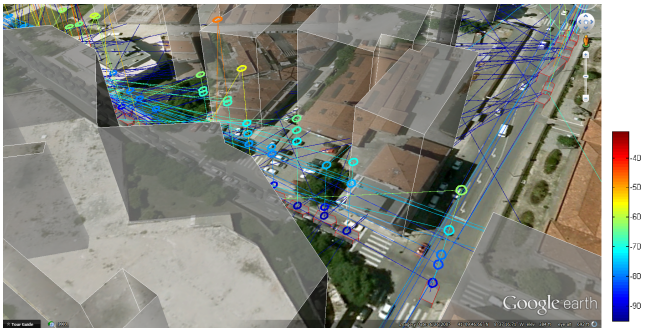
GEMV^2 requires the following functions available at MATLAB Central File Exchange: `http://www.mathworks.com/matlabcentral`.

- deg2utm and utm2deg © 2006 by Rafael Palacios: `http://www.mathworks.com/matlabcentral/fileexchange/10915` and `http://www.mathworks.com/matlabcentral/fileexchange/10914`
- Line Simplification © 2009 by Wolfgang Schwanghart: `http://www.mathworks.com/matlabcentral/fileexchange/21132`

[2] `http://www.google.com/earth/`
[3] `http://en.wikipedia.org/wiki/Virtual_globe`



(a) Snapshot showing a part of transmit-receive pairs in the city of Porto.



(b) Street-level view.

Figure 1: Visualization of received power generated by GEMV^2. Color bars are in dBm.

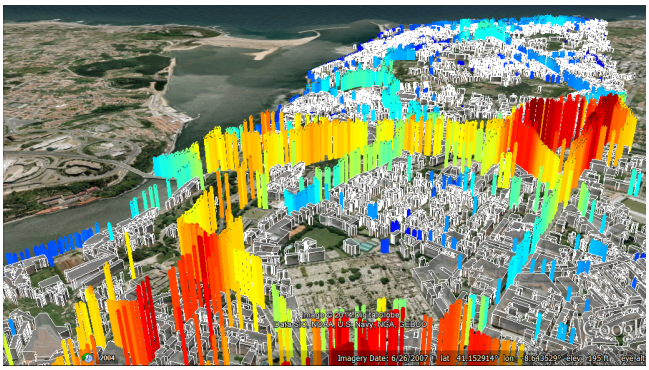


Figure 2: Visualization of neighborhood size generated by GEMV^2.

- Google Earth Toolbox © 2012 by Scott Lee Davis: `http://www.mathworks.com/matlabcentral/fileexchange/12954`
- Fast and Robust Curve Intersections © 2006 by Douglas Schwarz `http://www.mathworks.com/matlabcentral/fileexchange/11837`
- Line-Line Intersection (2d) © 2012 by Sebastian W: `http://www.mathworks.com/matlabcentral/fileexchange/35606`
- OpenStreetMap Functions © 2012 by Ioannis Filippidis: `http://www.mathworks.com/matlabcentral/fileexchange/35819`
- Fast Range Search through JIT (ver 2) © 2009 by Yi Cao: `http://www.mathworks.com/matlabcentral/fileexchange/19480`
- xml2struct © 2010 by Wouter Falkena: `http://www.mathworks.com/matlabcentral/fileexchange/28518`

These functions are copyrighted by their respective authors and licensed under the BSD license. For convenience, they are included in the GEMV^2 package in the `+externalCode` directory, along with their respective licenses. Some functions were modified to suit the purpose of GEMV^2. Google Earth Toolbox and OpenStreetMap Functions are elaborate toolboxes with many functionalities not required by GEMV^2. Therefore, the minimum set of required functions from these toolboxes is included in GEMV^2 package. The original versions of functions can be downloaded from the MATLAB Central File Exchange as indicated above.

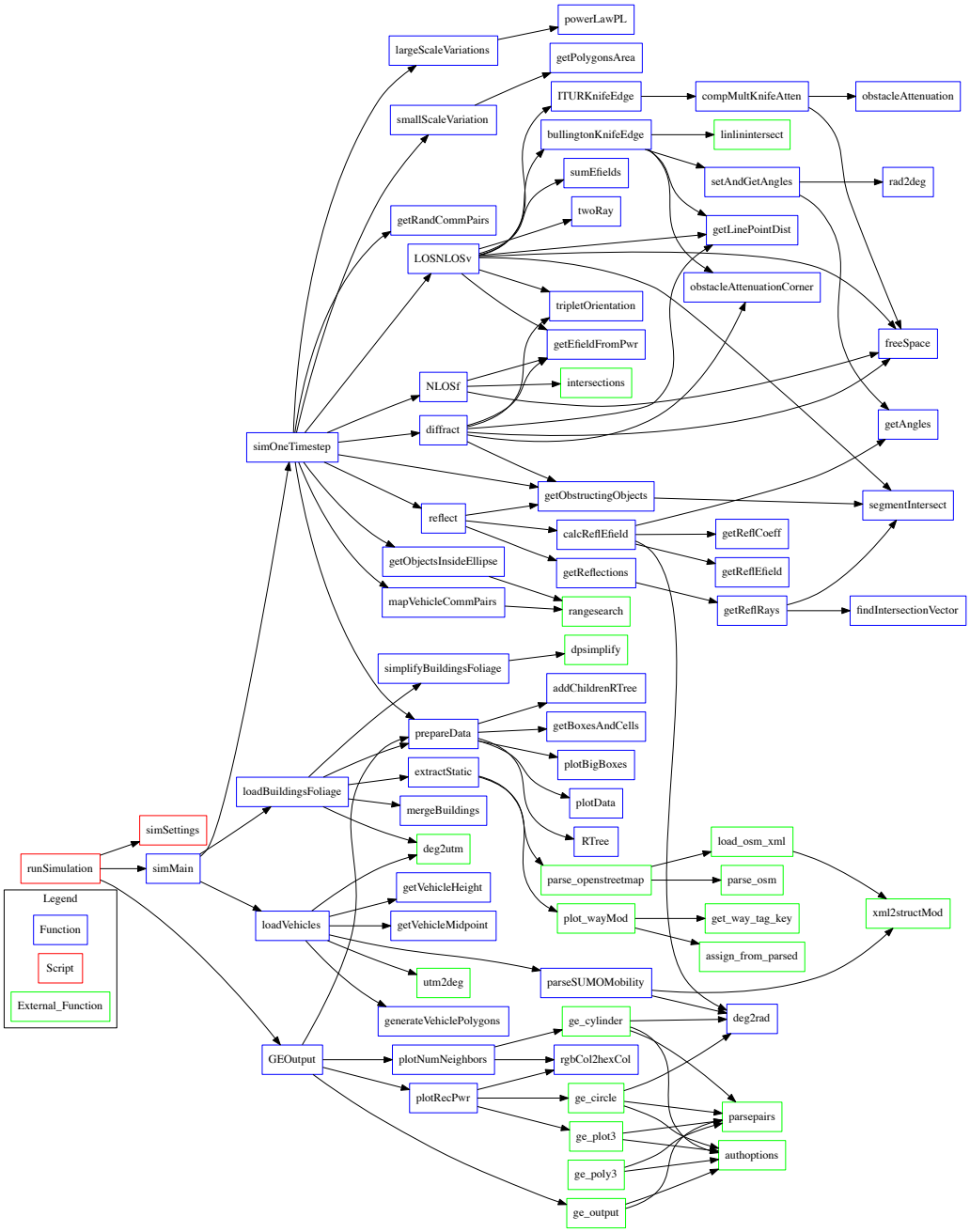


Figure 3: GEMV^2 function dependencies.

2.5 What is in the package?

The complete GEMV^2 `.zip` package contains the following:

1. GEMV^2 code.
2. GEMV^2 license.
3. This user manual.
4. Dataset collected via aerial photography, containing buildings and vehicles in the city of Porto, Portugal, obtained through the DRIVE-IN project and described in Ferreira et al. [6]. This dataset is highly precise and can be used as a starting point for the simulations.
5. Since Porto dataset contains only a single time-step, in addition to it, packaged with GEMV^2 you will find building and foliage outlines extracted from OpenStreetMap [3], representing a part of downtown Cologne, Germany. For vehicular mobility in Cologne, the package contains a preprocessed SUMO [2] file generated using TAPAS Cologne scenario. Running GEMV^2 with this dataset results in 100 simulated seconds. Additionally, in the package there is a dataset with 20 simulated seconds in Newcastle, UK.

3 Building and Foliage Outlines

3.1 Using Outlines of Buildings and Foliage from OpenStreetMap

The outlines of buildings and foliage are available from OpenStreetMap [3], which is the most comprehensive free geographical database. That said, the actual representation of buildings and (particularly) foliage in the OpenStreetMap can be limited, with many objects missing. You need to be judicious where you perform simulations, since a database missing a lot of buildings and foliage will likely result in unrealistic simulation output.

Buildings and foliage can be imported into MATLAB using the OpenStreetMap Functions package available at `http://www.mathworks.com/matlabcentral/fileexchange/35819`. A version of the package has been included with the model. It was modified to output a three-column array `[objectID | Latitude | Longitude]`, each row representing one point of an object.

To use buildings and foliage from OpenStreetMap other than those already included in GEMV^2 package, simply go to `http://www.openstreetmap.org` and export the objects for a desired location. Then, point the variable `staticFile`

in simSettings.m to the downloaded .osm file. This will invoke the OpenStreetMap parser and save the processed data into an array, so that the conversion is performed only once.

If you plan to run the simulation over a large area (e.g., an entire city), follow these steps:

1. Download .osm or .pbf file containing desired simulation area from sources indicated on the OpenStreetMap website: http://wiki.openstreetmap.org/wiki/Downloading_data
2. Get the .osm file for the specified region (defined with southwestern and northeastern bounding points) using osmconvert (http://wiki.openstreetmap.org/wiki/Osmconvert#Clipping_based_on_Longitude_and_Latitude):

   ```
   osmconvert bigArea.pbf -b=-75.8,45.1,-75.7,45.2 > cityArea.osm
   ```

3. To further reduce the osm file, you can filter out unnecessary objects using osmfilter (http://wiki.openstreetmap.org/wiki/Osmfilter):

   ```
   osmfilter cityArea.osm --keep="building" --keep="shop"
   --keep="amenity" --keep="landuse" --keep="forest"
   --keep="natural" --keep="wood" --keep="tree"
   --keep="tree_row" -o=cityAreaPoly.osm
   ```

In practice, the input .osm file containing buildings and foliage can be up to approximately 50 MB in size. This limitation is mainly due to xml2struct function (www.mathworks.com/matlabcentral/fileexchange/28518), which requires approximately 5-10 times the size of .osm file in memory when converting the .osm file to MATLAB structure).

3.2 Converting Shapefiles to OpenStreetMap

If you have buildings and foliage in shapefile format, to use them with GEMV^2, one option is to first convert the data to OpenStreetMap format. This can be done using the shp-to-osm.jar utility available at http://wiki.openstreetmap.org/wiki/Shp-to-osm.jar (related GitHub project is located at: https://github.com/iandees/shp-to-osm/downloads). The conversion has been successfully tested with version shp-to-osm-0.8.6-jar-with-dependencies.jar (available on GitHub). Example of usage:

```
java -cp shp-to-osm-0.8.6-jar-with-dependencies.jar
com.yellowbkpk.geo.shp.Main --shapefile inputPolygons.shp
--rulesfile RULES.TXT --osmfile outputOSM.osm
--outputFormat osmc --maxnodes 100000000
```

Once the OSM files have been generated, they can be converted to the simulator-readable array as explained in Section 3.1.

4 Vehicular Mobility and Outlines: SUMO Floating Car Data

Vehicular mobility generated by SUMO can be used as input for GEMV^2. The function `parseSUMOMobility.m` converts SUMO XML output to a five-column array `[ID | Latitude | Longitude | vehicleType | bearing]`, which is then converted to the three-column array `[objectID | Latitude | Longitude]` using the function `generateVehiclePolygons.m`.

First, export the vehicular mobility from SUMO by using –fcd-output option and outputting latitudes and longitudes. For example, in Windows:

```
sumo.exe -c sumoCfgFile.cfg --fcd-output SUMOMobility.xml
--fcd-output.geo true
```

Next, use `SUMOMobility.xml` as input to GEMV^2. In terms of the size of the input SUMO mobility file, same considerations apply as in Section 3.1.

5 Referencing GEMV^2

If you find GEMV^2 useful in your work, please cite the following reference [1]:
Mate Boban, João Barros, and Ozan K. Tonguz: "Geometry-Based Vehicle-to-Vehicle Channel Modeling for Large-Scale Simulation," IEEE Transactions on Vehicular Technology, 2014, doi:10.1109/TVT.2014.2317803 [PDF][BIB]

If you primarily use "vehicles as obstacles" model implemented as part of GEMV^2, please cite the following reference [7]:
Mate Boban, Tiago T. V. Vinhoza, Michel Ferreira, João Barros, and Ozan K. Tonguz, "Impact of Vehicles as Obstacles in Vehicular Ad Hoc Networks," IEEE Journal on Selected Areas in Communications, vol. 29, no. 1, pp. 15–28, January 2011, doi:10.1109/JSAC.2011.110103 [PDF][BIB]

Acknowledgements

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References

[1] M. Boban, J. Barros, and O. Tonguz, "Geometry-based vehicle-to-vehicle channel modeling for large-scale simulation," *IEEE Transactions on Vehicular Technology*, vol. PP, no. 99, pp. 1–1, 2014.

[2] D. Krajzewicz, G. Hertkorn, C. Rössel, and P. Wagner, "SUMO (simulation of urban mobility)," in *Proc. of the 4th Middle East Symposium on Simulation and Modelling*, 2002, pp. 183–187.

[3] M. Haklay and P. Weber, "OpenStreetMap: User-generated street maps," *IEEE Pervasive Computing*, vol. 7, no. 4, pp. 12–18, 2008.

[4] D. G. Bell, F. Kuehnel, C. Maxwell, R. Kim, K. Kasraie, T. Gaskins, P. Hogan, and J. Coughlan, "NASA World Wind: Opensource GIS for mission operations," in *IEEE Aerospace Conference*, 2007, pp. 1–9.

[5] M. Boban, "Demo: Visualization of vehicular communication: Insights into power, effective range, clustering, and neighborhood size," in *IEEE Vehicular Networking Conference (VNC 2014)*, December 2014, pp. 205–206.

[6] M. Ferreira, H. Conceição, R. Fernandes, and O. K. Tonguz, "Stereoscopic aerial photography: an alternative to model-based urban mobility approaches," in *Proceedings of the Sixth ACM International Workshop on VehiculAr Inter-NETworking (VANET 2009)*. ACM New York, NY, USA, 2009.

[7] M. Boban, T. T. V. Vinhoza, M. Ferreira, J. Barros, and O. K. Tonguz, "Impact of vehicles as obstacles in vehicular ad hoc networks," *IEEE Journal on Selected Areas in Communications*, vol. 29, no. 1, pp. 15–28, January 2011.