Spatial Design of Transmitter-Receiver-Constellations for PCL-Systems using GIS based Visibility Analysis

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Abstract: Passive Coherent Location (PCL) requires detailed knowledge about the geometric transceiver-receiver-constellations and the technical parameters for simulating the effective field of view. Geographic Information Systems (GIS) provide tools to fuse spatial information with technical metadata to evaluate individual geometric constellations and obtain optimal radar coverage. This paper presents a GIS-based model procedure for planning a passive radar system using base stations of the Global System for Mobile Communications (GSM) as illuminator. The implementation of GIS-technology allows analyzing spatial information about illuminated areas in combination with the underlying technical metadata.

1 Introduction

During the last decades PCL radar has been established as a subset of bistatic radar with various types of signals for illumination (e.g. DAB, DVB, FM signals). The high global distribution of the GSM technology dedicates this system as an ideal illuminator for passive radar [ZNW09, LTS07]. Furthermore, all Base Transceiver Stations (BTS) send individual signals with constant power which makes it easy to identify each signal [TSL+05a]. A central task when installing such a system is the geometric evaluation of variable receiver locations in relation to the BTS which can be considered constant in location, transmitting frequency, orientation and antenna characteristics.
Mobile telecommunication companies use GIS-based visibility analyses in the field of network planning [vL02]. For the considered application we extend the classical visibility analysis methods by combining the illuminated areas with the technical parameters of the original transmitter station. Finally, the results are checked against the observation space of receiving antenna to determine the effective field of view. The results of this investigation proof the usability of GIS-based spatial analysis in the field of data fusion for the geometric planning of a GSM-based passive radar system.

2 GSM based passive radar

In contrary to the conventional (active) radars, PCL systems use electromagnetic signals of multiple foreign, non-cooperative transmitters as illuminators. With its multiple transmitters PCL is considered as a subtype of a bistatic radar constellation and should be treated as a multi-static constellation (see fig. 1) [Nic10]. The receiver antenna compares the direct reference signal from the transmitter stations and the target echo for locating the target position. The whole system is controlled by the receiver configuration as variable part of the system [TSL05b].

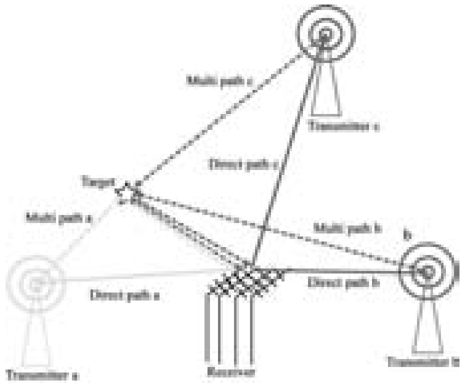

Figure 1: Passive radar schema

Each sending unit serves one grid cell within the telecommunication network. Arriving signals get identified by their individual Broadcast Channel (BCCH), the served network cell (Cell ID) and the Local Area Code (LAC). It requires extensive knowledge about all sending parameters of the serving station in order to interpret the reference signal and the run-time-difference to the echo signal correctly. To analyse the potentials of GSM-based PCL within a dedicated area three tasks have to be fulfilled:

1. Simulation of BTS illuminated areas
2. Simulation of observed areas for individual receiver positions
3. Intersection of both to calculate the effective field of view

3 Visibility analysis for PCL planning

With regard to passive radar applications, the knowledge about the accessible field of view in a network of multiple independent transmitters is essential. The determination of visible areas from one or more given observation points is a key feature of geographic data processing [Coo05, KRW97, LTS07].

3.1 Viewshed analysis

ESRI's ArcGIS 9.3.1 provides a viewshed tool that determines visible areas within the continuous surface of a Digital Elevation Models (DEM) to a set of observer features [ESR10b]. The tool calculates a Line-of-Sight (LOS) between each raster cell and the observer location. To verify if an object can be seen from a certain location, the elevation angle from the observer to the object is checked against all elevation points of the surface on a straight line between the observer and the target. If only one profile point has a greater elevation angle than the object, it has to be classified as not visible (see fig. 2) [KRW97].

Figure 2: Let P equal a set of profile points $\{p1, p2, p3, ..., pn\}$. If $\exists$ a point pi$_{\in}$ P where θ_{pi} ¿ θ_{object} the object is not line-of-sight (taken from [KRW97]).

The fact that radio waves get absorbed by intervening topography makes visibility analysis to an appropriate method for simulations in the field of radar applications [EA08]. It is favourable to use a Digital Terrain Model (DTM) instead of the DEM because it takes all surface objects into account that could blockade the radio wave propagation. In the case of radar applications, visibility can be interpreted as illumination in space [Ric10].
When simulating radio wave propagations the different behaviour of electromagnetic and optical waves has to be taken into account. Depending on the frequency (or wave length) this is often achieved with a correction of the earth diameter and the refractivity coefficient of visible light in the air. The default settings for these two parameters in ArcGIS are 12740 km as diameter and 0.13 as refractivity coefficient. The formula for the correction of surface and elevation units reads [ESR10a]:

$$Z_{actual} = Z_{Surface} - \frac{Dist^2}{Diam_{Earth}} + R_{refr} \cdot \frac{Dist^2}{Diam_{Earth}} \tag{1}$$

$Dist$ is the planimetric distance between the observation feature and the observed location, while $Diam_{Earth}$ and R_{refr} denote the diameter of the earth and the refractivity coefficient of visible light in the air. The implementation of the Fresnel zone could improve the approximation and deliver more precise simulation results.

3.2 Extended visibility analysis

Whereas classical visibility tools only return a raster dataset that divides the surface into visible and non-visible areas, the requirements for radio wave propagations are more complex. Passive radar systems need information which transmitters illuminate a particular part of the observation room. To extend the results of the visibility analysis it is necessary to fuse the results with additional information about the transmitter location, frequencies and other metadata. Due to the limited information capacity of a raster, it is advisable to use vector formats instead. Therefore, a new GIS algorithm was developed in Python to extend the capabilities of the standard viewshed tool (see fig. 3) [Ric10].

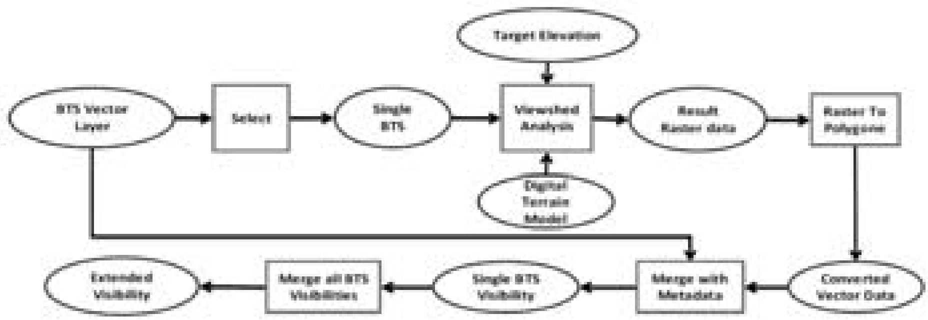

Figure 3: Function scheme for the extended viewshed analysis

The fundamental problem of visibility analysis is to identify the locations on the surface which can be seen from a single observer position [KRW97]. This would generally exclude the detection of air targets. The new extended viewshed tool involves a "Target Elevation" parameter to consider air targets. While the transmitter parameters in a GSM network are considered as constant, the tool can be used in a batch process to simulate the visibility for multiple target elevations in one turn. Thus, it is possible to build a database of illuminations for different target elevations. With these results, it is possible to evaluate the entire observation room with regard to all parameters from multiple transmitters including possible intersections of illuminations (see fig. 4). The tool performance strongly depends on the number of transmitters, the spatial extent and the raster resolution of the DTM.

3.3 Effective observation space

Although the transmitter illumination is a key factor for PCL observation, the total system also strongly depends on the physical settings of the receiving antenna. Only the combination of transmitters and receiver allows the determination of the effective spatial observation space [Ric10]. Therefore, another tool was developed that simulates the view-

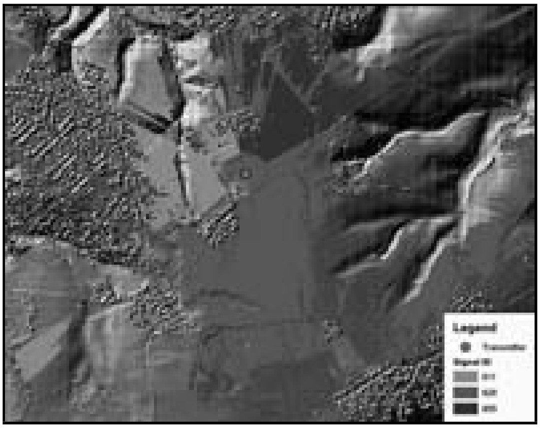

Figure 4: Visibility analysis for a single base station with three transmitter antennas

shed for individual receiver locations and intersects the results with the polygons from the extended visibility tool). The user sets the parameters for the receiver position, observation direction and target elevation. The resulting polygons contain the transmitter parameters and represent the effective observation space for the chosen receiver settings.

Figure 5: Effective passive radar observation potential

4 Results

This paper shows the potentials of GIS-based visibility analysis as an approach to radio wave propagations for PCL applications. Due to the particular requirements of PCL, it was necessary to extend the classical methods to fuse multiple transmitters with individual technical parameters for comprehensive evaluations. The results of the new extended viewshed tool intersected with the receiver's observation space returns the effective field of view for passive radar applications for a given spatial extent. Even if the common visibility tool does not simulate the electromagnetic wave propagation it is sufficient for preliminary investigations on PCL. The case study uses GSM base stations as illuminators but the overall concept could also be adapted to other frequencies (e.g. FM radio, DVB-T, etc.) as well. Further investigations could involve reflection characteristics or the approximation to the real radio wave propagation.

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