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Analyzing the Impact of ITS Mobile Node Antenna HPBW on Primary Network SINR

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The development of communication systems worldwide provides an additional load on both licensed and unlicensed spectrum. One of the biggest segments influencing the unlicensed one is Intelligent Transportation Systems (ITS) as part of the Smart City paradigm. One of the potential solutions to reduce the interference picture is by improving the spatial reuse of the system, i.e., by utilizing directional antennas on the vehicle side. This work aims to analyze the radiation pattern spatial characteristics of the antenna installed on the vehicle to be developed for cases when static ITS infrastructure nodes are located on the roadside light poles and primary network operating in the same frequency range is located in different locations: same light pole; roadside unit; or building. As a result, the recommendations regarding the antenna parameters are given for each case.

Key words and phrases: V2I, ITS, antenna analysis, HPBW, SINR.

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1. Introduction and background

Today, the number of the Internet of Things (IoT) nodes is growing tremendously [1]. One of the most significant IoT market niches is indeed related to vehicular communications [2]. The connectivity opportunities between mobile nodes regarding standardization have already taken shape, and the first deployments would face the market soon forming the paradigm of Intelligent Transportation System (ITS) [3, 4].

The communications between vehicles in ITS are commonly classified into two big groups: vehicle-to-vehicle (V2V) [5] and vehicle-to-infrastructure (V2I) communications [6]. Some researchers combine them into Vehicle-to-Everything giant [7, 8]. Conventionally, the wireless links in both cases were utilizing omnidirectional antennas for the data exchange. However, this approach may remarkably influence already deployed networks operating within the same frequency spectrum and, thus, new solutions should be developed aiming at decreasing the signal-to-noise ration on the primary (already deployed or prioritized) networks.

One of the examples to be utilized is the implementation of smart antenna arrays allowing to enable additional spatial reuse by producing narrow radiation pattern main beam and nulls in interference directions and the possibility of diversity on the receiving and transmitting side [9]. The other option is to utilize antenna steering solutions [10, 11] that require more space concerning deployment but are generally cheaper to develop. The use of any of the solutions provides higher throughput, better reliability, and lower interference. This work provides a vision of how the spatial antenna characteristics allow reducing the signal to interference plus noise ratio of the primary network while the ITS radio network is considered as secondary one.

Antenna arrays allow to control their radiation patterns and specify the characteristics by selecting the phase and amplitude excitations at the antenna elements [12]. Scanning arrays, in which the maximum of the radiation pattern can be oriented at different points in space, are based on controlling the phase excitation between the antenna elements. The proper amplitude-phase distribution of the individual antenna elements makes it possible to form the required radiation pattern by controlling the main characteristics of the antenna array, such as the half power beamwidth (HPBW), beamforming direction, sile lobe level (SLL), etc.

Adaptive antenna arrays are a separate class of devices [13]. Due to the availability of an adaptive processor, such antenna systems can dynamically adapt to changes in the surrounding signal and interference environment, forming nulls in interference directions and radiation maximum in the target signal arrival direction. In this work, authors do not utilize systems with adaptive processors because due to initial conditionals all target and interference signal directions of arrival are known in before so that no complex algorithms are needed. Moreover, according to previously developed analytical model [14] there was an assumption that at all points of the mobile node antenna are oriented with radiation maximum pointing towards static nodes of the secondary network while moving the radiation pattern.

The rest of the paper is organized as follows. The description of the ITS antenna solutions is given in Section 2. The system model is given in Section 3. Numerical results are provided in Section 4. The last section concludes the paper.

2. Directed antenna solutions for ITS

The architecture of antenna solutions with dynamic directivity control of the main beam was discussed in many works [9, 15] as a promising solution concerning economical expenditures in comparison with full adaptation systems. The beam switching technology is more straightforward to implement since the beamforming arrangement can be designed by applying matrix adders – the Butler matri [16] and the Blass matrix [17]. These matrices are multipoles, and their inputs are connected to the outputs of the antenna array individual elements, and the outputs correspond to specific beams. Such matrices consist of directional couplers and phase shifters.

Another solution is to use sector antenna arrays with the fixed shape radiation pattern [18]. In this case, the main beam of each antenna array covers a specific sector of angles. These solutions could be used on the stationary unit side. Such configuration may lead to the intersection in the space of the beams of contiguous antenna arrays. Thus, the target signal could be received by a number of directional antenna arrays but with different strength. The most straightforward algorithm for determining the target signal angle of arrival is based on the signal strength analysis, thus choosing the beam (and therefore the angle sector) where the signal strength has its maximum. Such a system requires a switching mechanism that processes the connection of each sector antenna array with a standalone receiver.

One more approach is to use electronic beam scanning in a passive antenna array with electronic control of parasitic reactive elements. This solution allows to generate the main beam in a given direction and to adapt to sources of interference with low computational complexity. This solution consists of one active radiating element and a number of passive parasitic elements located at a short distance from the central active one and representing a reactive load. The angular direction of the beam depends on the reactive impedance of the parasitic elements and can be determined using a matching circuit based on an electronically controlled varactor diode. The advantage is the absence of feeder paths to individual elements since the currents in the elements are induced by electromagnetic coupling. The elements are located at small distances from each other to ensure sufficient electromagnetic interaction, and such compactness makes this solution suitable for placement on the roof of the vehicle.

The fourth solution is based on using one receiver and antenna array with digital beamforming technique [19]. Traditional signal processing with digital beamforming represents the simultaneous processing of the signal incident at individual antenna array elements and, thus, requires that the number of receivers be equal to the number of antenna elements. However, for compact and inexpensive solutions, the use of several receivers is unjustified. One of the alternative methods is based on the local antenna elements spatial multiplexing. This method corresponds to the sequential switching on/off of individual antenna elements. The disadvantage of this system is the phase shift caused by the time delay while switching between individual antenna elements. These phase shifts can be compensated for, as the switching time is known.

Adaptive antenna systems with electronic or electro-mechanical beam scanning also allow controlling the direction of the radiation maximum and the position of nulls. Thus, such antennas can adapt to changing signal-to-interference conditions. Adaptive antennas are more complicated to implement because they require an adaptive processor. An example of a solution with partial adaptation is a phased array antenna (PAA) with digital phase shifters [20]. The adaptation criterion is based on minimizing the output power of the interfering signals. The brute force method is not practical for the static nodes with a large number of elements and multi-bit phase shifters, but as solutions for ITS, when the antenna array can be two to four elemental, and phase shifters are controlled by several bits (have a coarse discretization), this technique is entirely justified.

3. System model

The system model is shown in Fig. 1. Here, we consider the most straightforward scenario when the vehicle is approaching the closest static receiver of the secondary network Rx_0 (transmitter's beam is formed towards the corresponding receiver) and produce interference to the primary static network Rx_1 receiver. Rx_1 is positioned horizontally. The transmitter on the mobile node Tx_0 has a directive antenna with is approximated as a die pyramid with the corresponding α_v and α_h characteristics. The height of the Tx_0 installation with respect to the ground level is h_1.

Typically, Rx_0 is located on the roadside infrastructure, i.e., light poles, public transport stops, etc. Considering the metropolitan scenario, such installations happen every 30–60 meters and the antenna placement height h_2 may vary. The height of Rx_1 is equal to h_3 meters.

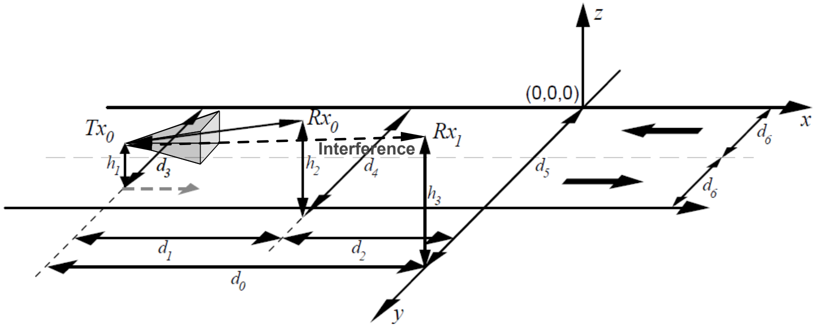

Figure 1. Scenario of interest

The distance between the nodes of the secondary network, mobile Tx_0 and static Rx_0, is represented by d_1 and could vary from 100 to 0 meters, which represents the mobile node movement. Value d_2 describes the distance between Rx_0 and Rx_1 and is set to 5 meters in this work. The distance d_3 from the edge of the road to Tx_0 is 3 meters. Values d_4 and d_5 represent the distances from the edge of the road to Rx_0 and Rx_1 correspondingly.

For the channel path loss, we have utilized 3GPP 38.901 model for UMi (PL_1, PL_2) and InH if the distance between target equipement is less than 10 meters (PL_0) [21].

$$PL_{UMi-LOS} = \begin{cases} PL_0, \text{ if } 1m \leq (d_1 + d_2) \leq 10m \\ PL_1, \text{ if } 10m \leq (d_1 + d_2) \leq d_{BP} \\ PL_2, \text{ if } d_{BP} \leq (d_1 + d_2) \leq 5km \end{cases},$$

where

$$PL_0 = 32.4 + 17.3log_{10}(d_I) + 20log_{10}(f_c),$$
$$PL_1 = 32.4 + 21log_{10}(d_I) + 20log_{10}(f_c),$$
$$PL_2 = 32.4 + 40log_{10}(d_I) + 20log_{10}(f_c) - 9.5log_{10}(d_{BP}^2 + (h_3 - h_1)^2),$$

and the threshold is calculated as

$$d_{BP} = 4(h_3 - h_e)(h_1 - h_e)\frac{f_c}{f},$$

where f_c – is the central carrier frequency, $c = 3 \cdot 10^8$ m/s – is the speed of light, the effective height are calculated as h_3 and h_1 equal $h_3 = h_3 - h_e$ meters, $h_1 = h_1 - h_e$ meters, h_e meters – is the parameter related to the vehicle height. For UMi h_e is selected as 1 meter according to the specification.

Let us further consider three scenarios of interest: (i) The first scenario represents the case when Rx_0 and Rx_1 are located in the same physical location. Here $d_4 = d_5$ meters. (ii) In the second scenario, Rx_0 is located at the light pole while Rx_1 is moved on the height of the 3rd floor of the nearby building. (ii) The third scenario corresponds to situations when Rx_0 is located at the light pole while Rx_1 is on the roof of the public transport stop (roadside unit).

Table 1

Main system parameters

Parameter	Value
Frequency band	4.900 – 5.925 GHz
Rx_1 sensitivity	−68 dBm
Rx_1 antenna gain	23 dBi
Rx_1 antenna HPBW	8^ox 8^o
Tx_0 Tx power	19 dBm

The primary network equipment is a wireless bridge Tsunami Quick Bridge 8200 that allows providing high-speed backhaul access for the Internet providers [22]. The main system parameters are given in Table 1.

4. Numerical results

The numerical evaluation was executed in the MatLab 2018a environment. The target of interest in this paper is to compare the SINR on the primary network receiver side with the allowable value based on the receiver sensitivity while the target modulation is QAM-64 and the PER equal 10%. Thus, the reliable operational value of the primary network is 27 dB. In order to evaluate the mobile node antenna, we change the HPBW of the Tx_0 antenna from 10 to 40 degrees in both panes. The Rx_0 antenna is supposed to be a sector antenna covering the approaching vehicle side of the road.

The results of the first scenario are given in Fig. 2. Since in this work we only focus on smart antenna beam control, we assume that scanning antenna array, which is based on phase excitation at antenna elements, is used. Note, HPBW and SLL are changing with different scan angles. In could be concluded that HPBW in elevation plane has almost no influence on the Rx_1 SINR. This is mainly due to the lack of height difference between Rx_0 and Rx_1. Here, for most of the vehicle position (45–100 meters from the receiver), the SINR falls within acceptable bounds. While analyzing smaller distances, it could be concluded that effective HPBW is azimuth plane should be smaller than 15^o. Lowering it also provides better results in a trade-off to the developed antenna cost due to the need to increase the number of antenna elements.

Fig. 3 represents the second scenario. Similarly to the previous case, the effective primary network operation is reached in some vehicle locations. In contrast, the regions with acceptable SINR has slightly increased due to the better spatial separation of Rx_0 and Rx_1. Note, the ineffective operation may be faced in close proximity between Tx_0 and Rx_0 due to non-zero side-lobe interference.

The third scenario results are shown in Fig. 4. Here, Rx_1 is located on the road-side units. Here, the propagation characteristics follow the same pattern as in previous scenarios.

5. Conclusions

Based on the obtained results, it could be concluded that for real-life ITS scenario with vehicular node equipped with a smart antenna, the antenna HPBW in azimuth plane should be not more than 15 degrees taking into account the aim to minimize negative influence on the primary network. HPBW in elevation plane is not such a critical parameter, however, the narrower the beam, the better the value of the SINR.

The authors are currently developing the smart antenna system prototype which would fulfill the obtained in this paper requirements.

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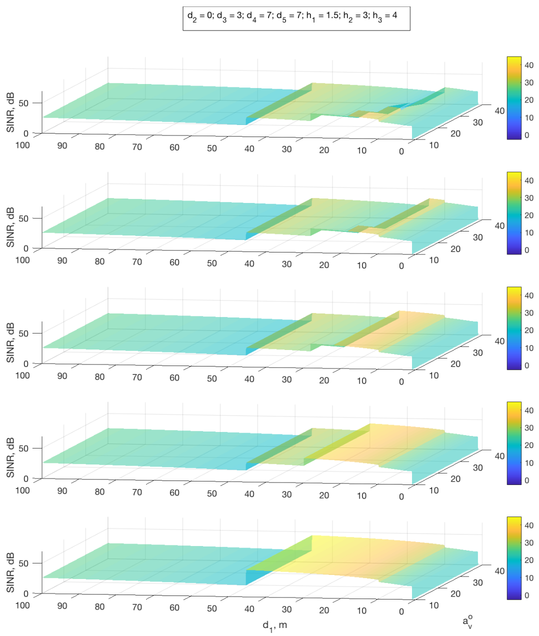

Figure 2. Placement of Rx_0 and Rx_1 on the light pole

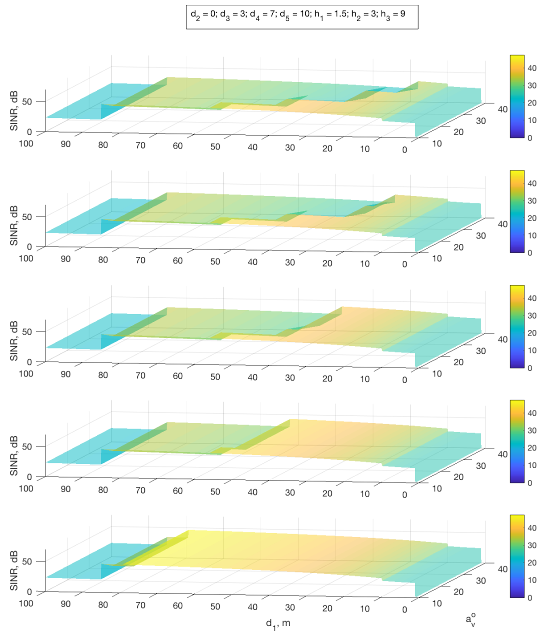

Figure 3. Placement of Rx_0 on the light pole and Rx_1 on the building

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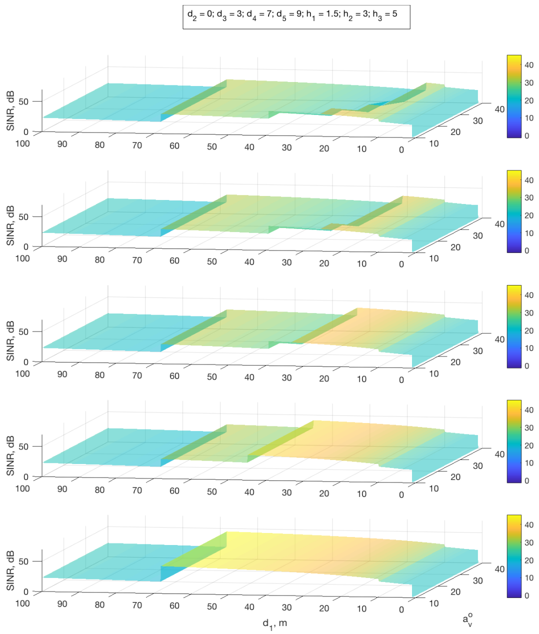

Figure 4. Placement of Rx_0 on the light pole and Rx_1 on the road side unit

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