A Planning Tool for TV White Space Deployments

A Technical Report

by

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Abstract

There have been numerous studies conducted on the availability of TV white spaces in India, which show that white spaces are plentiful. If one needs to harness this spectrum, there is a need for techniques to compute suitable locations where secondary base stations can be placed for providing broadband access. To address this issue, we have come up with a planning tool which determines the best locations for placement of secondary antennas based on secondary base station's coverage area, population of the region, throughput required and other such parameters. Our real-time model uses different propagation models to compute the path loss, and subsequently the throughput using Shannon's theorem, to determine the optimal placement of secondary TV white space antennas. Experiments with our tool show that it can provide good placement of secondary base stations and provide high throughput to the covered users. We believe that a tool like ours can accelerate the pace of deployment of secondary networks in the TV white space spectrum.

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1 Introduction

TV white space refers to the unutilized television spectrum licensed by a regulatory authority. Within the frequency spectrum, UHF (Ultra High Frequency) band is of particular interest since it has very good wireless radio propagation characteristics. In a comprehensive study involving the estimation of available TV white space in India [13], it has been found that almost 75% of the areas in India have all the 15 channels in the 470-590 MHz spectrum available as white space. This large amount of white space spectrum can be put to use for providing internet access especially in rural areas where the broadband penetration is quite low. The goal of our work is to develop a tool for determining the optimal locations where the secondary TV antennas can be placed, in regions where primary TV transmitters are sparse. We envision that Wi-Fi access points will be available at the secondary base stations to extend the coverage of the base station to non-UHF clients.

Using the tool that we have developed, TV white space researchers can get an idea of how to plan the deployment of secondary white space antennas for providing Wi-Fi coverage. Our tool makes real-time on-the-fly calculations using theoretical models, and does not require actual deployment tests. Our tool takes as input estimates of TV white spaces available at a location (e.g., using databases like [4]), and information about population density and altitude. Using this information, and the minimum required throughput to users, our tool decides on the optimal placement of secondary TV white space transmitters that can provide broadband connectivity to a region. Our tool is particularly useful to cover large swathes of rural areas in countries like India to provide broadband connectivity using TV white spaces. This work does not take into account the economic aspects involved in the deployment of TVWS antennas.

Our main contributions are as follows:

- Estimation of optimal locations of secondary base stations in the TV white space spectrum (in terms of secondary coverage area and throughput achieved) using different propagation models and demographic features like population and altitude values.
- Development of a Graphical User Interface (GUI) for easily using the above theoretical model.

The rest of the report is organized as follows. Section 2 describes the design of the tool and the theoretical model, and presents an overview of the GUI of the tool. Section 3 describes the performance comparison of our work with other algorithms with an Indian dataset. Section 4 talks about work done in this field and tells how our work is different from others. Finally, Section 5 presents the concluding remarks and directions for future work.

2 Design

In this section, we first discuss the various metrics that can be used to pick locations for placing secondary antennas in a TV white space (TVWS) network, and propose a new metric for antenna deployment. Our work is open-source and the tool can be accessed via [10].

2.1 Criteria for selection of base stations

It is a well known fact that the altitude of a place of the base station is an important factor in determining the coverage area and the end user throughput. But using just the geographic radio coverage area as a metric for TVWS antenna placement can lead to placing an antenna at a place with a high altitude and high coverage radius, but a low population being served around it. Therefore, coverage area by itself is not a good metric since it does not take into account the population of the places within its coverage. On the other hand, selecting a place for TVWS antenna based on population alone is also not a good idea since it may be the case that the place has a high population but a very low altitude, requiring many base stations. As a consequence, we define a metric called the *weighted utility* which takes into account both the coverage area and population while determining the places to be selected as TVWS transmitters. This metric ensures that the place selected for TVWS deployment has a proper balance between the coverage area and the population it serves. The formula for weighted utility is as follows:

$$\text{Weighted Utility} \leftarrow \frac{\text{Users}^2[\text{d}_1] \times \text{U}[\text{d}_1] + ... + \text{Users}^2[\text{d}_\text{n}] \times \text{U}[\text{d}_\text{n}]}{\text{Users}[\text{d}_1] + ... + \text{Users}[\text{d}_\text{n}]} \tag{1}$$

where

$$\begin{aligned} \text{U}[\text{d}_\text{n}] &= \text{value of utility function at 'n' kms distance} \\ \text{Users}[\text{d}_\text{n}] &= \text{number of people within 'n' kms from a place} \end{aligned}$$

The utility function is defined by the following equation:

$$\text{U}[\text{d}_\text{n}] \leftarrow \frac{\text{Throughput at distance 'd}_\text{n}\text{'}}{\text{Bandwidth required per user} \times \text{No. of users within 'd}_\text{n}\text{'}} \tag{2}$$

In the calculation of utility function, we consider the throughput obtained at each of the locations which are within the coverage radius of a potential TVWS antenna, illustrated in Figure 1. We then divide the throughput by the total bandwidth requirement of the population within that region. In this way, we ensure that both the coverage area and population are taken into account while calculating the utility function. In order to give more weightage to those places having a higher population, we take a weighted value of the utility function and include it while calculating our weighted utility metric.

2.2 Throughput calculations

We use a theoretical model based on Shannon's theory to calculate the throughput at any distance. We calculate the throughput T_p at distance d_n as follows:

$$\begin{aligned} T_p[d_n] &= B_w \times \log_2(1 + S[d_n]/N) \\ S[d_n] &= \mathrm{P}_{\mathrm{transmit}} - L_p[d_n] \end{aligned} \tag{3}$$

where

$T_p[d_n]$	= throughput at distance of 'd_n' kms (Mbps)
B_w	= channel bandwidth (MHz)
$S[d_n]$	= signal at distance of 'd_n' kms (Watts)
$P_{transmit}$	= Transmit Power (dBm)
L_p	= Path loss at distance of 'd_n' kms (dBm)
N	= thermal noise (Watts)

The path loss affects the utility inversely. This is because as the path loss increases, the throughput decreases, and since the utility is directly proportional to the throughput according to equation 2, therefore the utility decreases with the increase in path loss.

According to various field strength measurements conducted in India, it has been found that Hata model is the best suited for capturing propagation modeling [14]. We make use of this model for calculating path loss. It is applicable to three types of environment: *urban, suburban, and rural*. The median path-loss for these environments can be calculated as described in [8] Since this model works for base station antenna heights in the range of 30 to 200 metres, we therefore limit the places in our input whose altitude falls in this range. Also, we consider our secondary mobile station to be at a height of 1.5 metres from the ground level.

For comparing the performance of our tool across various types of terrain considerations, we use other propagation models. Egli is a model for propagation which does not consider the elevation profile of the terrain between the sender and the receiver. It is usually applied in cases where there is a constant line-of-sight transmission between a fixed antenna and a mobile antenna and where transmission happens over an irregular terrain [3].

Free-space model is the most simple among all the propagation models and it is often used in white space availability experiments [11]. Free space model's loss is proportional to the square of the distance between the sender and receiver. It does not depend on the height of the base antenna and the mobile antenna. Also, it is proportional to the square of the channel frequency. Therefore, free space path loss increases a lot over distance and frequency [7].

Plane earth model is another propagation model we use for comparison. It considers the direct path between the sender and receiver and the reflection from ground. Its path loss does not depend on the channel frequency.

2.3 Algorithm

Our work takes the following parameters as inputs and produces secondary TVWS locations and their weighted average throughputs as output.

Input: Place, population, latitude, longitude, altitude, bandwidth requirement per user
Output: Secondary transmitter locations, weighted average throughputs

Following steps describe the algorithm used for computing the locations for secondary TVWS base stations. For each place given in the input

1. Calculate the coverage radius based on the altitude.
2. Find all the locations and the distances of those locations which fall within its coverage radius. See Figure 1.
3. Within the coverage radius of each place, run the propagation model for calculating the path loss at all those distances where other locations are situated. Also, find the corresponding throughput, utility and weighted utility of each place using equations 3, 2, 1 respectively.
4. We follow a greedy algorithm for white space antenna placement. From the list of places, select the place which has the highest weighted utility and cover all the locations present within its radius.
5. Remove the place which is selected as the secondary transmitter and the locations it covers from the list of places in the input.

6. Repeat the above two steps till all the places given in the input are not covered.

7. Based on the places which are selected for white space antenna placement and the locations they cover, run the propagation model again for calculating the path loss at all those distances where those locations are present.

8. Also, find the corresponding weighted average throughput for each place where the secondary antenna will be deployed.

$$\text{Weighted average throughput} \leftarrow \frac{\text{Users}[d_1] * T_p[d_1] + ... + \text{Users}[d_n] * T_p[d_n]}{\text{Users}[d_1] + ... + \text{Users}[d_n]}$$

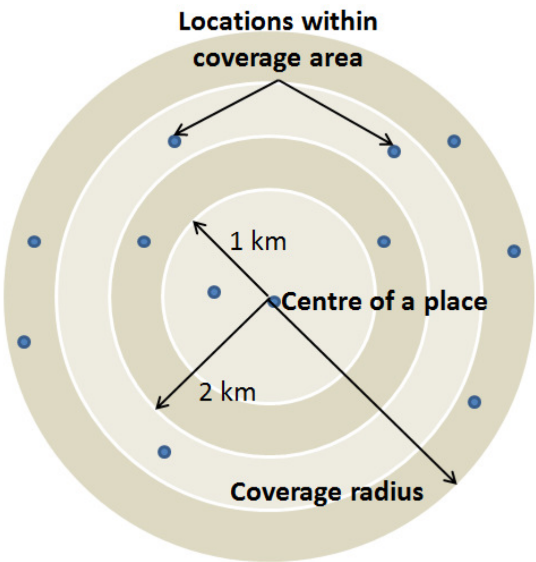

Figure 1: Illustration of the coverage area of a place.

2.4 Datasets

The TVWS tool is tested on Thane Rural dataset. This dataset contains 400 locations along with population, latitude, longitude, and altitude information. Thane is one of the most densely populated districts in India having a large rural population. We now describe the method of data collection for the dataset.

The Government of India's census website [9] provides a district-wise demographic information about the list of cities/towns/villages and their corresponding population. We have the demographic information as per the 2011 census. Using this data, we run Python scripts to calculate the latitude, longitude and altitude of the places using Google's Geocoding and Elevation APIs [6] [5]. For all places, we assume as input the average bandwidth (in Mbps) required per user.

For Thane Rural datasets, we consider the input places as rural and use the path loss calculations of Hata model for rural areas. The received power or the signal power is the difference between the transmit power and the path loss. We assume a fixed secondary transmit power of 36 dBm for all the places since close to 100% places have all the white space available. As per a study conducted by the World Bank [15] about internet penetration in India, it is found that only 10% of the population had access to the internet in 2011, the year for which we have the census statistics. So we consider only 10% population as input in all the locations across Thane Rural dataset. The secondary antenna height is assumed to be 30 metres. Table 1 summarizes the various parameters supplied as input to the Thane datasets. Algorithm 2.3 provides a description of the placement of secondary antennas.

Parameter	Thane Dataset
Environment Type	Rural
Receiver Sensitivity	-96 dBm
Secondary Transmit Power	36 dBm
TVWS Frequency	470 MHz
Channel Width	8 MHz
Bandwidth required per user	0.5 Mbps
TVWS Antenna Height	30 m
Number of datasets	20
Locations within each dataset	20

Table 1: Input parameters.

2.5 Graphical User Interface of the planning tool

The tool [10] for TVWS network deployment is integrated with Google Maps for displaying the location of secondary base stations. Figure 2 shows a sample output of the execution on our tool. The list of places to be covered for planning TVWS deployment can be either selected by using import or auto-pick option. Also, the user can easily switch between various propagation models using a drop-down list. When the front end interface is executed, PHP and MySQL scripts running at the back end determine the optimal locations for placing secondary white space antennas and display them on a Google Map.

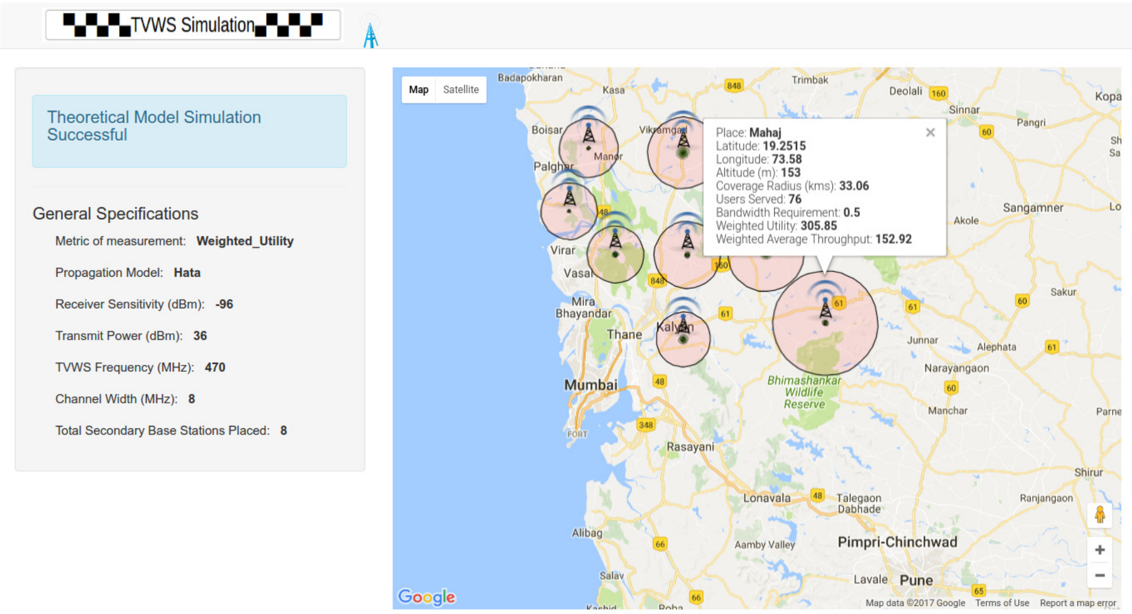

Figure 2: Sample output of the TVWS planning tool.

3 Evaluation

We compare our weighted utility algorithm with two other algorithms - one which picks base stations based on the coverage, and the other which picks base stations using population. In coverage algorithm, we select the secondary antennas in decreasing order of coverage area while in population algorithm, we pick places according to decreasing population. Except for step 5, remaining steps are the same as described in algorithm 2.3.

For evaluation, we find that comparing the minimum of weighted average throughputs is the best indicator of the goodness of our algorithm. It is observed that the minimum weighted average throughput is maximized in the weighted utility case, as opposed to the other two algorithms.

Figure 3 depicts the CDF of minimum weighted average throughputs for coverage, weighted utility and population algorithms on 20 different datasets across Thane Rural. Weighted utility performs the best as compared to coverage and population since it considers those locations which have a high population as well as a high altitude for TVWS placement. As a consequence, the minimum throughput obtained is the highest among all the three algorithms. The coverage algorithm performs the worst since the datasets contain many high altitude places with low population. So the weighted average throughput falls as a result of less people being present within the coverage radius of a high altitude location. For Thane Rural, population algorithm produces intermediate results as it considers the number of people around a location but does not consider altitude at all. Also, the population algorithm has the lowest minimum weighted average throughput because of almost uniform population throughout all places.

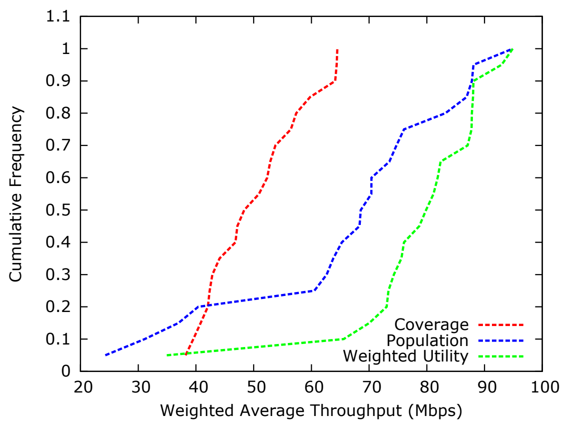

Figure 3: CDF of minimum of weighted average throughputs across datasets for Hata model in Thane.

Figures 4, 5, 6 show the CDF of minimum weighted average throughputs for Egli, Free Space and Plane Earth models respectively. We can observe that our weighted utility algorithm performs the best across all the propagation models.

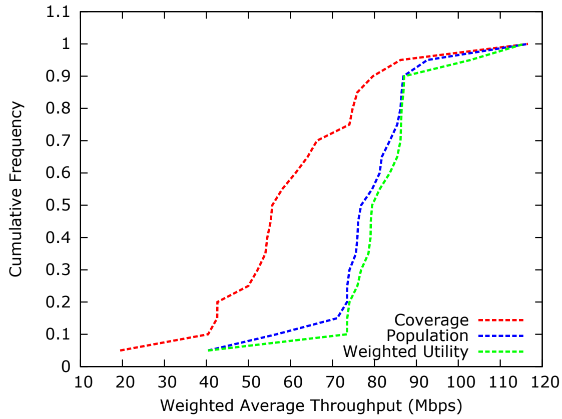

Figure 4: CDF of minimum of weighted average throughputs across datasets for Egli model in Thane.

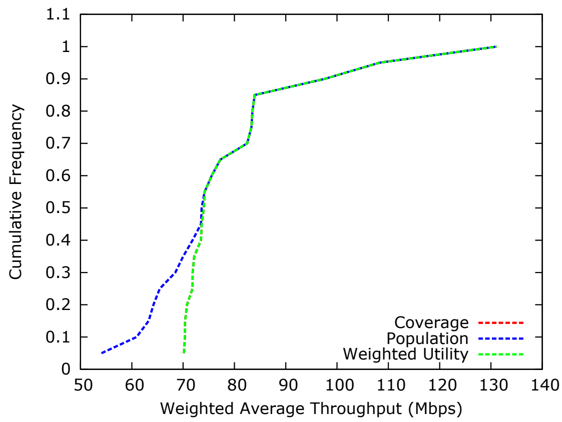

Figure 5: CDF of minimum of weighted average throughputs across datasets for Free Space model in Thane.

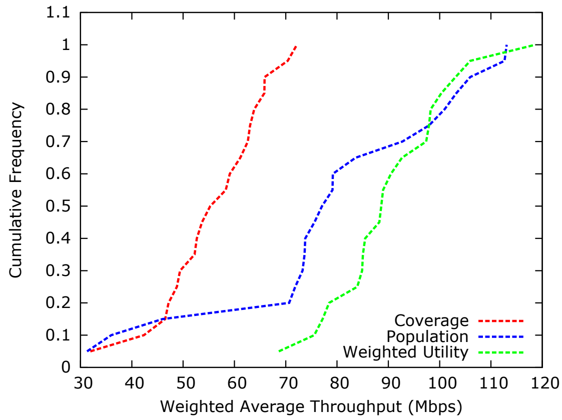

Figure 6: CDF of minimum of weighted average throughputs across datasets for Plane Earth model in Thane.

Figure 7 depicts the CDF of number of secondary transmitters required for coverage, weighted utility and population algorithms on Thane Rural datasets. As expected, coverage algorithm requires the least number of TVWS antennas for Thane datasets since antenna locations are selected in decreasing order of coverage area.

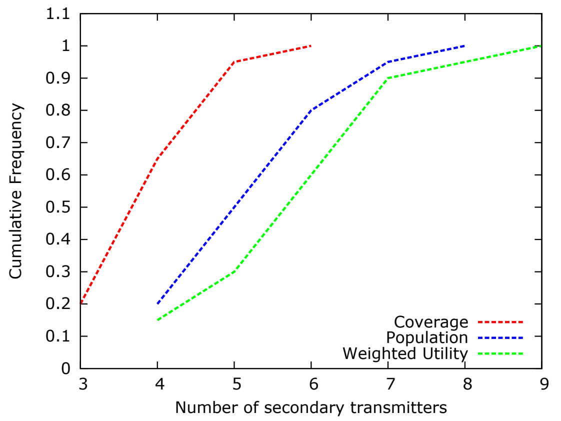

Figure 7: CDF of number of secondary transmitters required for Hata model in Thane.

Overall, we can conclude that the minimum weighted average throughput is maximum in the case of weighted utility algorithm for both Thane Rural datasets.

4 Related Work

There have been numerous studies done in the field of radio network planning tools, which optimize a number of metrics and are applicable to a wide variety of networks like GSM, UMTS, LTE, Wi-Fi etc. ASSET [1] is one such tool which has functionalities like propagation modeling, coverage map generation, traffic modeling, neighbor planning etc. Our work addresses the secondary network planning for TVWS, an area which has seen an increase in research in recent years. However, most of this research is related to spectrum sensing techniques or design enhancements in TVWS databases. KNOWS [2] deals with the design of a platform which is spectrum aware so as to utilize white spaces of varying bandwidths. In SenseLess [12], white space devices are dependent on a central database to estimate the white space availability as opposed to spectrum sensing. White space is estimated using a database of primary spectrum occupants and sophisticated propagation modeling. WISER [16] explores white spaces in indoor locations motivated by the fact that 70% of the spectrum demand comes from indoor locations. It is designed for identification and tracking of indoor white spaces, without requiring spectrum sensing.

Our work is orthogonal to these contributions in the sense that we propose a planning heuristic given that TVWS databases show the white space spectrum as available. Major research in TVWS is centered around the estimation of white space availability while our work is meant to enhance the planning efforts in using the available white space.

5 Conclusion

We have implemented a secondary white space planning tool based on a theoretical model using various propagation models (Egli, Free Space, Hata and Plane Earth) and Shannon's theorem. An algorithm to compute the optimal locations for deploying secondary antennas is also described. We put together all of this in a graphical environment which is easy to understand and use. The end user has the freedom of planning TVWS deployment for any location in India and the world provided he/she has the required input in standard format. This work can be further extended by comparing our computing tool with real deployments to see if the base station locations given by our tool make sense.

References

[1] ASSET, 2016, "ASSET - Radio Network Planning Tool for GSM, UMTS, LTE and 5G," http://www.teoco.com/products/planning-optimization/asset-radio-planning/

[2] Bahl, P., Chandra, R., Chou, P., Ferrell, J., Moscibroda, T., Narlanka, S., and Wu, Y., 2007, "Knows: Kognitiv networking over white spaces," in *IEEE DySPAN*, p. 32.

[3] Egli, J. J., 1957, "Radio propagation above 40 mc over irregular terrain," *Proceedings of the IRE*, 1383–1391.

[4] Ghosh, S., Naik, G., Kumar, A., and Karandikar, A., 2015, "Openpaws: An open source paws and uhf tv white space database implementation for india," in *Communications (NCC), 2015 Twenty First National Conference on* (IEEE). pp. 1–6.

[5] Google, 2016, "Google Elevation API," https://developers.google.com/maps/documentation/elevation/start

[6] Google, 2016, "Google Geocoding API," https://developers.google.com/maps/documentation/geocoding/start

[7] Harvard, 2016, "Radio Propagation Models," http://people.seas.harvard.edu/~jones/es151/prop_models/propagation.html

[8] Hata, M., 1980, "Empirical formula for propagation loss in land mobile radio services," *IEEE transactions on Vehicular Technology*, 317–325.

[9] India, 2016, "Census of India Website," http://censusindia.gov.in/

[10] Iyer, M., 2016, "TVWS Planning Tool," https://www.cse.iitb.ac.in/~tvws/tvws_tool/Thane/client.html

[11] Mauwa, H., Bagula, A. B., Zennaro, M., and Lusilao-Zodi, G.-A., 2015, "On the impact of propagation models on tv white spaces measurements in africa," in *Emerging*

Trends in Networks and Computer Communications (ETNCC), 2015 International Conference on (IEEE). pp. 148–154.

[12] Murty, R., Chandra, R., Moscibroda, T., and Bahl, P., 2012, "Senseless: A database-driven white spaces network," *IEEE Transactions on Mobile Computing*, 189–203.

[13] Naik, G., Singhal, S., Kumar, A., and Karandikar, A., 2014, "Quantitative assessment of tv white space in india," in *Communications (NCC), 2014 Twentieth National Conference on* (IEEE). pp. 1–6.

[14] Prasad, M., and Ahmad, I., 1997, "Comparison of some path loss prediction methods with vhf/uhf measurements," *IEEE transactions on broadcasting*, 459–486.

[15] WorldBank, 2016, "World Bank Growth Indicators," `http://data.worldbank.org/indicator/IT.NET.USER.P2?locations=IN`

[16] Ying, X., Zhang, J., Yan, L., Zhang, G., Chen, M., and Chandra, R., 2013, "Exploring indoor white spaces in metropolises," in *Proceedings of the 19th annual international conference on Mobile computing & networking* (ACM). pp. 255–266.