Vol 8. No. 1 Issue 2 – May, 2015

African Journal of Computing & ICT

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A Frequency Planning Model for Spatial White Space in GSM Cellular Network

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ABSTRACT

This work proposes a new approach to better utilization of the radio spectrum in the GSM 900 and 1800 Band, taking advantage of the cellular concept of the GSM radio and the cognitive driven dynamic spectrum access of the next generation wireless technology. The unused channels of a system, within the coverage area, of a particular cell, were identified as spectrum holes, and otherwise referred to as channel holes, in this paper. A model for this system-created, GSM spatial whitespace was formulated. Using the coverage radius of a cell, antenna directivity and other engineering parameters together with frequency planning map of a GSM operator in Ilorin, the capital city of Kwara state in Nigeria, a computation of potential available bandwidth within the coverage area of some GSM cells was done to demonstrate the model. The quantity of white space that can be recovered per cell, shows that there exists higher potential for secondary cognitive usage of the GSM 900 and 1800 band than claimed in reports of several, previous spectrum occupancy measurements. A comparison of the utilization level by this approach with some other works revealed a considerable increase in recoverable spectrum holes in the two GSM bands combined.

Keywords—Frequency planning, Spatial White Space, Spectrum utilization, opportunistic secondary access, channel holes

African Journal of Computing & ICT Reference Format:
S.O. Onidare, A.A. Ayeni, O.B. Ayeni & A.O. Ajagbe (2015): A Frequency Planning Model for Spatial White Space in GSM Cellular Network. Afr J. of Comp & ICTs. Vol 8, No. 1, Issue 1. Pp 199-208

1. INTRODUCTION

The use of radio spectrum for communication has been beset with the challenge of interference, a source of lowering quality of service (Qos), since time immemorial. The finite nature of the radio spectrum vis-a-vis the ever increasing demand for the same spectrum by emerging technologies worsens the challenge, which, naturally task the ingenuity of practitioners. Efforts at addressing this challenge, led to the realization that the scarce radio spectrum is grossly under-utilized, hence optimization of the available spectrum became a priority.

The un-utilized portion, of the licensed spectrum, known as *spectrum holes* or *white-spaces,* is categorized, mainly, as spatial or temporal. The exploitation for use, of these spectrum holes or white-spaces is one of the main achievements of research efforts, aimed at improving the radio spectrum utilization profile. However, to date, less attention has been given to utilizing the white space in the GSM and UMTS Bands, when compared with the attention received by other bands, in the radio spectrum. Exploitation and utilization of the TV white space, TVWS, has received one of the highest attentions among the bands in the radio spectrum. Consequently, utilization of the TVWS has been proposed to be used for services that are hitherto provided within the GSM band [1], [2], [3].

Even though, this is an encouraging proposition, it is opined that harvesting the holes in the GSM band will provide for a faster, less complex and cheaper adoption and implementation. Due to the volume of traffic and the nature of operation of a typical cellular mobile network, white spaces seem either non-existent or very negligible such that attempts at exploitation, in these bands, do not seem encouraging.

From the temporal perspective, spectrum occupancy measurements campaign conducted, world over, has revealed very high utilization level in the GSM bands and hence low and in some instances almost zero white space [4], [5], [6], [7], [8] etc. From the spatial perspective, the existence of white space in urban centre is regarded as a technological heresy, in the research world. Rather, the rural area was seen as the only cheap and viable option for better utilization of the spatial holes in the licensed GSM band [9].

This paper, examines the concept of spatial white space in the GSM band, from a different perspective, that derives its veracity from the mobile cellular network architectural framework. Using a service provider's network, the amount of spectrum that can be realized in the GSM bands in Ilorin, a sub-urban environment in North central Nigeria, was examined.

2. RELATED WORKS

For obvious reasons, the rural areas seem more appealing when exploitation of spectrum holes becomes an issue. This section chronicles some of the previous works along this line. The research work of [9] proposed a dynamic spectrum sharing model, the Nomadic GSM that is aimed at increasing the proliferation of Community Cellular Network. The work proposed the regulation of GSM white spaces for dynamic spectrum sharing, as in TV white space, as this will support the growth of community cellular networks, especially in the developing countries where rural access to communication services has left a lot to be desired. Authors of [10], proposed an 'Efficient Duty Cycle Model' to facilitate the reuse of GSM white space for cognitive femtocell access. The authors carried out a 'real scene' spectrum measurement in the GSM uplink in order to capture short duration signals and GSM hopping signals. The measurement was aimed at determining the spectral dynamics of the GSM network, in other words, the temporal white space in the network. From the evaluation done, it was opined that an additional 21.4 MHz can be farmed for cognitive femtocell use.

In [11] a spectrum occupancy measurement in was conducted in Chicago, Washington and other US cities in all bands between 30 MHz and 3,000 MHz. The overall usage for the cities was 13.1% for New York and 17.4% for Chicago. However, the frequency band for cell phone, expectedly, indicated high percentage utilization than the average for all bands in both cities. According to [12], the spectrum utilization of the GSM 900 and 1800 in India show higher potential for cognitive opportunistic secondary use in indoor environment as opposed to outdoor, and during the night as opposed to the day. Some frequencies, in the band, also holds more promise for secondary use than others while some are completely inaccessible for cognitive secondary access.

The results obtained also revealed a higher potential for secondary use, in the uplink channels, of 1800 MHz than the 900 MHz. The work presented in [13], was a spectrum occupancy measurement conducted to investigate spectrum utilization in Pretoria, South Africa, specifically in the TV, GSM 900 and GSM 1800 bands. The six week-long campaign indicated very high utilization in the GSM 900 band, while the GSM 1800 utilization, even though less than the GSM 900, is almost double the TV band utilization. Comparing the work with earlier works in this area; it is conclusive, either way, that the TV band holds more promise for cognitive secondary usage. The result of measurement of the utilization of 20 MHz to 3 GHz portion of the spectrum conducted in the Netherlands indicated a very high utilization of about 80% in the GSM 900 band [14]. Although the work considered the utilization level of GSM 1800, UMTS and the (Industrial, Scientific and Medical) ISM, the utilization level of these bands were not presented. In [15], the authors conducted spectrum occupancy measurements in the GSM 900 bands in two densely populated urban area of south Africa.

The measurement was done for three different operators in the two cities over a period of seven days. An inter-operator comparison expectedly showed differences in the utilization of each of the operators. The obtained result shows very high occupancy in the band and hence, does not show any exciting promise for cognitive secondary use. In [16], the result, of a two-day spectrum occupancy measurement, in the 70 MHz - 3 GHz frequency range reveals high utilization, in the GSM bands. Of, special, interest, is this work because of the resolution bandwidth or measurement slot of 100 KHz. The available bandwidth especially in the GSM bands was quantified by the number of measurement slots without activity. This work, even though, adopted a temporal approach provided an inspiration for the spatial approach employed in this paper.

3. MODELING OF THE GSM SPATIAL WHITE SPACE

Efficient utilization of the radio spectrum, through dynamic secondary (opportunistic) spectrum access, is the ultimate goal and driver of white space discovery and re-farming. The spatial white space concept, presented in this paper, is a modeling of the spectrum holes created as a result of the nature of the GSM cellular system design. It is based on the cellular concept and frequency re-use of a typical cellular system. The architecture of a cellular mobile system, involves the use of a small number of channels from the total available channels in a particular cell, thereby freeing up the remaining channels for secondary use within the coverage area of that cell.

From the foregoing, the following parameters are defined for the model presented in this work:

Each cell is a set of channels C_k

$$C_k = [\, c_1 \, . \, . \, . \, . \, . \, c_K \,] \qquad (1)$$

$K =$ *total no of channels allocated to a cell*

A channel is characterized by the vector

$$c_k = \|r\| \angle \varphi$$

where

r is the transceiver coverage radius and φ is the antenna Azimuth which characterized the coverage sector of each transceiver

Therefore:

$$C_k = [\, \|r\| \angle \varphi_1 \, . \, . \, . \, . \, . \, . \, . \, . \, . \, . \, \|r\| \angle \varphi_s \,] \qquad (2)$$

$$\varphi_s - \varphi_{s-1} = {}^{2\pi}/_{s} \qquad (3)$$

assuming a cell coverage of 2π *radian*

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Consequently, the total coverage area A of a system is given by $A \in R^{n \times K}$

$$A = \begin{bmatrix} \|r_{11}\|\angle\varphi_1 & \cdots & \|r_{1k}\|\angle\varphi_s \\ \vdots & \ddots & \vdots \\ \|r_{n1}\|\angle\varphi_1 & \cdots & \|r_{nk}\|\angle\varphi_s \end{bmatrix} \qquad (4)$$

n is the total no of cells in an area/system, while K is the no of channels allocated to each cell

Similarly the distance between the cells D is modelled as a symmetric positive semi definite matrix given by:

$$D \in R^{n \times n} \mid D = D^T, D \geq 0 \qquad (5)$$

$$D = \begin{bmatrix} 0 & d_{12} & \cdots & \cdots & d_{1n-1} & d_{1n} \\ d_{21} & 0 & \cdots & \cdots & \vdots & \vdots \\ \vdots & \vdots & \ddots & \cdots & \vdots & \vdots \\ \vdots & \vdots & \cdots & \ddots & \vdots & \vdots \\ \vdots & \vdots & \cdots & \cdots & 0 & d_{n-1n} \\ d_{n1} & d_{n2} & \cdots & \cdots & d_{nn-1} & 0 \end{bmatrix}$$

Idealistically, assuming adjacent cell coverage areas do not overlap, the vacant channels c_v (channel holes) in a particular cell, that can be used by a cognitive secondary user, is simply the difference between sum total of channels available in a system and the total no of channels allocated to the cell servicing that geographical area. i.e

$$\sum c_v = \sum c_T - \sum c_k \qquad (6)$$

However, because in reality cell coverage areas, especially in urban centers, do overlap in order to avoid/prevent *gaps in the network coverage*, the probability of the equation (6) above defining the vacant channels within a cell coverage area is approximately zero. To obtain a more realistic estimate of vacant channels in a cell area, cognizance must be taken of all the overlap channels from neighbouring cells. Thus:

$$\sum c_v = \sum c_T - \left(\sum c_k + \sum_J \sum_K C_j c_k \cap \sum c_k \right) \qquad (7)$$

The second term in the parenthesis in the equation (7) represents the number of k channels (c_k) in J neighbouring cells C_j that overlaps with a particular cell C_k. (Note: $C_k = \sum c_k$). Thus the equation can be reduced to

$$\sum c_v = \sum c_T - \left(\sum c_k + \sum c_{kj} \right) \qquad (8)$$

i.e
$\sum c_{kj} = \sum_j \sum_k C_j c_k \cap \sum c_k$, where c_{kj} is the occupied channel(s) due to overlapping channels of j neighbouring cells into a particular cell C_k.

Assume the coverage area C_A of each cell can be modeled as a norm ball of radius r and centre C_o given by:

$$C_A = \{ C \mid \|C - C_o\| \leq r \} \qquad (9)$$

C_A consists of all points C within the norm ball of the cell . C_A is assumed to be symmetrical about the origin.

From the foregoing, the system coverage area, especially of an urban centre, designed to have overlapping cell area, is a multiple intersections of norm balls. This intersection of cells can be mathematically defined in terms of the distance between sets (recall from equation (1), that a cell is a set of channels) as:

$$dist\left(C_{A_k}, \sum_j C_{A_j} \right) = \inf\left\{ \|r_k - r_j\| \,\middle|\, r_k \in C_{A_k}, r_j \in C_{A_j} \right\} = 0 \qquad (10)$$

where C_{A_k}, is the coverage area of a reference cell, $\sum_j C_{A_j}$, refers to all the neighboring cells, while r_k and r_j are the transceiver coverage range/radius of the reference cell and its neighbour cells respectively.

Therefore, if equation (10) holds, then:

$$\|r_k - r_j\| > d_{kj}^{*} \qquad (11)$$

where d_{kj} is the distance between reference cell and a neighbour cell.

From equation (11), (2), and (3), the number of overlap channels between a reference cell and each of its neighbour cells can then be computed from the expression below:

.

$$c_{kj} = \begin{cases} \sum_{i=1}^{k} c_i, \text{when } \|r_k\| > d_{kj} \\ \sum_{i=1}^{l} c_i, \text{ when } \|r_k\| + \|r_j\| > d_{kj}, \ \varphi_k - \pi/s \leq \varphi_j \leq \varphi_k + \pi/s \\ 0, otherwise, \end{cases} \qquad (12)$$

$(l \subset k)$, φ_k and φ_j are the azimuth of the reference cell and neighbour cell(s) transceiver respectively.

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4. A CASE STUDY QUANTIFICATION OF THE PROPOSED GSM SPATIAL WHITE SPACE MODEL

This section is divided into two. The first part provides a brief overview of the GSM frequency allocation in Nigeria, while the second presents the results of computation of white space that can be recovered using the approach/model proposed in this paper.

(a) Overview of the GSM Spectrum Allocation in Nigeria

Nigeria belongs to the ITU frequency allocation region 1 (there are three regions worldwide), hence the Nigeria Communication Commission (NCC) allocated frequency range of 890 - 915 MHz (Uplink or Reverse channel), 935 - 960 MHz (Downlink or Forward channel) for the GSM 900 service and 1710 - 1785 MHz (Uplink or Reverse channel), 1805 - 1880 MHz (Downlink or Forward channel) for the GSM 1800 service on a primary basis [19]. The spectrum is divided between five (5) operators as shown in Tables 1 and 2. From Tables 1 and 2, each GSM service operator in Nigeria is allocated 5 MHz in the 900 band and 15 MHz in the 1800 Band making a total of 20 MHz.

Since the bandwidth of a single channel in GSM is 200 KHz, this gives 100 voice and control channels in both the uplink and downlink direction. The service operators used fixed channel assignment strategy in each of their cells.

(b) Computation of Channel Holes within a Cell coverage area.

The frequency planning map of a GSM service provider in Ilorin, capital city of Kwara state of Nigeria was used as a case study to demonstrate our model. The service operator used in this work, made use of 120^0 sectoral directional antenna in all their cells in Ilorin and its environs. A total of six (6) transceivers, three (3) for the 900 band and three (3) for the 1800 band, is the maximum number of transceivers used in any particular cell. Using the cell coverage radius and the antennas' direction, it is possible to determine the number of used channels within a cell coverage area, the number of overlapping channels and by implication the possible number of channels/spectrum available for secondary opportunistic use in that cell area. Table 3 shows the white space that can be recovered using this approach for a small portion of the GSM network in Ilorin, of the service operator earlier mentioned

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Table 1: GSM 900 Frequency Assignments in Nigeria [17]

GSM 900 ASSIGNMENT					
OPERATOR	**ETISALAT**	**MTEL**	**GLO**	**MTN**	**AIRTEL**
T_X	935-940	940-945	945-950	950-955	955-960
R_X	890-895	895-900	900-905	905-910	910-915
STATES					
LAGOS	**ETISALAT**	**MTEL**	**GLO**	**MTN**	**AIRTEL**
OGUN					
ONDO					
OSUN					
EKITI					
OYO					
KWARA					
EDO					
DELTA					
RIVERS					
BAYELSA					
AKWA IBOM					
CROSS RIVER					
EBONYI					
ABIA					
IMO					
ANAMBRA					
ENUGU					
BENUE					
KOGI					
NIGER					
ABUJA					
NASSARAWA					
TARABA					
PLATEAU					
BAUCHI					
GOMBE					
ADAMAWA					
BORNO					
YOBE					
JIGAWA					
KANO					
KADUNA					
KATSINA					
ZAMFARA					
KEBBI					
SOKOTO					

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Table 2: GSM 1800 Frequency Assignment in Nigeria [18]

1800 MHz BAND-GSM					
OPERATOR	**MTEL**	**GLO**	**MTN**	**AIRTEL**	**ETISALAT**
T_X	1805-1820	1820-1835	1835-1850	1850-1865	1865-1880
R_X	1710-1725	1725-1740	1740-1755	1755-1770	1770-1785
STATES					
LAGOS	M-TEL	GLO	MTN	AIRTEL	ETISALAT
OGUN					
ONDO					
OSUN					
EKITI					
OYO					
KWARA					
EDO					
DELTA					
RIVERS					
BAYELSA					
AKWA IBOM					
CROSS RIVER					
EBONYI					
ABIA					
IMO					
ANAMBRA					
ENUGU					
BENUE					
KOGI					
NIGER					
ABUJA					
NASSARAWA					
TARABA					
PLATEAU					
BAUCHI					
GOMBE					
ADAMAWA					
BORNO					
YOBE					
JIGAWA					
KANO					
KADUNA					
KATSINA					
ZAMFARA					
KEBBI					
SOKOTO					

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Table 3: Computed Channel Holes of some selected Cells of a GSM Network in Ilorin

Cells	No. of used Channels	No. of Overlapping Channels	No of Channel Holes	White Space Bandwidth (MHz)
Cell 1	6	8	86	17.2
Cell 2	6	4	90	18.0
Cell 3	6	16	78	14.4
Cell 4	6	12	82	16.4
Cell 5	6	26	68	13.6
Cell 6	6	12	82	16.4
Cell 7	6	8	86	17.2

Table 3 shows that there exists, spectrum holes, for secondary opportunistic use, as a result of the cellular concept adoption, in the GSM technology. As seen from cell number 2 in the table above, about 90% of the allocated spectrum for this operator is available for secondary usage within the coverage area of the cell. Of course this value is not constant as demonstrated by the other cells presented in the table especially cell number 5 having about 68% available for secondary usage within its coverage area. The computation adopted the worst case scenario with respect to the number of overlapping neighbouring cells within the vicinity of a particular reference cell. The algorithm for the computation of the channel holes in table 1 is presented as follows:

Step 1:
1.1 ***Compute*** *cell radius of reference cell*
1.2 ***Compute*** *cell radius of neighbour cell*
1.3 ***Compute*** *distance between reference cell and neighbour cell*
Step 2: Compare
$\sum cell\ radius\ of\ reference + neighbour$ *cell with distance between cells*
2.1 ***If***
distance between cells
$> \sum cell\ radius\ of\ reference + neighbour$ *cell,*
2.2 compute channel holes (no overlap)
else
2.3 ***for***
distance between
$cells < \sum cell\ radius\ of\ reference + neighbour$ *cell,*
Step 3: check for number of overlap channels
3.1 ***if***
$radius\ of\ reference\ cell\ >$
$\sum\ radius\ of\ neighbour\ \ cell + distance\ between\ cells$
:
Overlap channels = total no of used cell in neighbour cell
3.2 ***then*** *go to 1.2*
else
$overlap\ channels = fraction\ of\ used\ channels\ in\ the\ neighbour\ cell$
3.4 ***then*** *go to 2.2*

end
end
end

5. COMPARING RECOVERABLE WHITE SPACE BY THIS MODEL WITH PREVIOUS WORKS

A comparison of the size of white space that can be recovered, using the model in this work and previous works involving spectrum occupancy measurements, showed that, this approach has potentials for more efficient utilization of the radio spectrum. For instance the spectrum occupancy measurements reported in [13], indicates approximately 90% utilization and 40% utilization for the GSM 900 and 1800 bands respectively. Extrapolating this to the case study of this work, gives a combined percentage utilization of about 52% of available bandwidth. This is a far cry from the utilization level obtained by this model in each cells which are 14%, 10%, 22%, 18%, 32%, 18%, and 14%, respectively for the few cells used in the computation of Table 1. Similar trends are noticed in the occupancy values reported in [11]; 54.8%, [14]; 42%, [15]; 60% - 90%, [20]; 37% - 59.5% in rural and 86% - 96.5% in urban, and [26]; 40.2%. It should however, be mentioned that further work of comprehensive measurement and computation spanning all the cells in the system will be needed to confirm this pattern.

Interestingly, an examination of the works reported in [21], [22], [23], [24], and [25], indicates that the recoverable white space possible in the GSM bands by this model can favorably compete with the existing TV white space. The works reported existing TV white space ranging from 4% - 96%. While some of the values of available usable bandwidth presented in the works are slightly higher than the ones presented in this work, some others are considerably lower.

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6. CONCLUSION

In this paper, it has been demonstrated that there exist the potential for freeing up more spectrum for dynamic access by taking advantage of the unused channels (channel holes) within the cell coverage area, of a typical cellular mobile system. By limiting a secondary operator's transceiver range, to within the coverage area of a particular cell, it is possible to make use of the frequency of the specific channel holes for service provision to subscribers within the cell coverage area. It therefore goes to say that the unused channels, identified as channel holes, are not universal, in a system, but are limited to within the coverage area of a particular cell.

This work has provided a template for an exhaustive quantification of the spectrum holes, of the whole system of this GSM operator and also for other operators, within the Ilorin metropolis. A GSM spatial white space map can be generated from this template, for the city and other cities. An experimental measurement campaign can be conducted to validate the existence of the quantified spectrum holes. Future works would also include development of a cognitive radio algorithm to provide a model for dynamic secondary access in future generation wireless technology. Validation of this algorithm can also be done with the availability of suitable test beds. Finally a framework for dynamic spectrum usage policy aimed at ensuring non-interfering secondary usage of this spectrum holes can also be provided for the regulators and policy makers.

ACKNOWLEDGMENT

This work was carried out under the auspices of the Communication and Network Research Group (CNRG) of the department of Telecommunication Science, University of Ilorin, Ilorin, Kwara State, Nigeria.

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