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Interference Temperature Model Based Technique for Dead Zone Elimination in Cognitive Radio Overlay Networks

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***Abstract*—Secondary Spectrum Access based on Interference Temperature is one of the options under Dynamic Spectrum Access which opens up licensed bands for spectrum efficiency. Optimizing this technique holds opportunity for many underutilized licensed bands. Most of the implementation so far deploys the unlicensed user with an independently located cell sites and this approach leads to dead zones or non-uniformities in the cell coverage and capacity. In this work, we investigate an appropriate location of the unlicensed user transmitter that eliminate the dead zones or non-uniformities and together with appropriate technique to reduce the interference level and enhance both coverage and capacity. Estimation of received signal levels at given location from transmitter is performed using the generalized signal propagation model. GSM 900 downlink channels is used for simulation to illustrate the principle. The results show that co-locating the unlicensed transmitter with the primary user is the appropriate location in secondary spectrum access based on interference temperature to eliminate coverage dead zones, and additionally, using spread spectrum reduces the interference and enhances coverage and capacity.**

Keywords—Interference Temperature, Dynamic spectrum access, Spread spectrum technique, Non-uniform cell, Co-location,

1. INTRODUCTION

Frequency spectrum refers to the sum total of bandwidths available for communication which is normally between 30 KHz and 300GHz. The need to use wireless for communication is growing so fast but this is hugely constrained by the fact that the frequency spectrum is a limited resource. The current static policy of spectrum management for the past decades of assigning portions of spectrum for exclusive use has been found to be ineffective. Its general objective is to protect these licensees who normally pay huge sums for these spectrum rights from harmful interferences. Based on this policy, huge portions of the spectrum have been assigned already for dedicated use and current USA Frequency allocation given in [1] shows that there is little room for any new allocation in the useful RF band (<30GHz) as seen in Fig. 1. It was effective in restraining encroachment resulting into these harmful interferences as technology had not much advanced in managing interferences as we have today

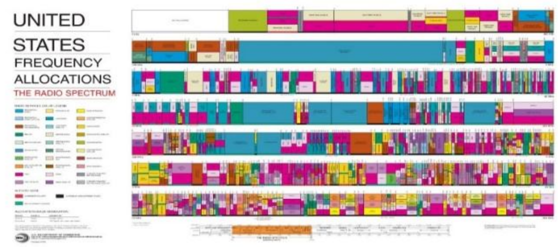

Fig. 1 Frequency Spectrum Allocation in USA

However, research by FCC in the USA [2] and Ofcom of the UK [3] shows that the average utilization of these assigned bandwidths is as low as 5% and some of this results is seen in Fig. 2. Other lab research which was done to measure signal energy over the various frequency bandwidth reveals very little signal energy in most of the bandwidths, with only significant signal energy around the 900MHz and the 1800MHz mainly due to the GSM cellular networks [4] and this results in seen in Fig. 3 below.

This management policy has led to an artificial spectrum scarcity in that most of the usable bands have been assigned for exclusive use although there are huge white spaces within these licensed bands. The situation is obviously unsustainable and poses serious threat to the rising demand for wireless communication.

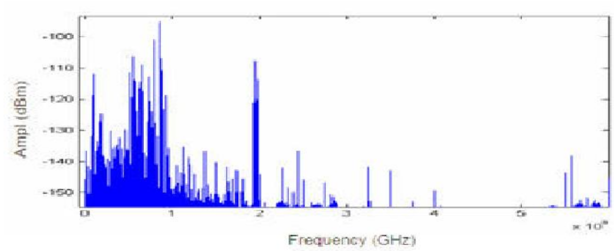

Fig. 2 Snap short of spectrum utilization up to 6GHz in urban area taken at Mid-day

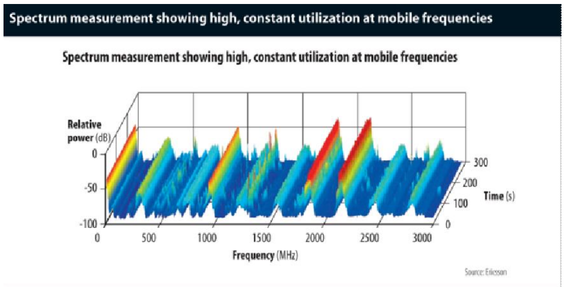

Fig. 3 Frequency Spectrum Measurement

The situation has led to the need for a change in the current paradigm for a rather more sustainable and spectrum efficient management approach. Various researches, discussion and debates has arisen out of this and led to spectrum management topics such as Spectrum Property Rights, Spectrum Commons, Dynamic Spectrum Access, Underlay and Overlay Spectrum Accesses. The profound conclusion among these is the subject Dynamic Spectrum Access DSA which effectively encompasses almost all the various management approaches including the current static spectrum management policy [5]. The various ideas presented at the first IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN) suggest the extent of this idea. Under this model, there is flexibility in spectrum access and assignment is based on need which brings efficiency. The broad categorization of the concept is shown in Fig. 4

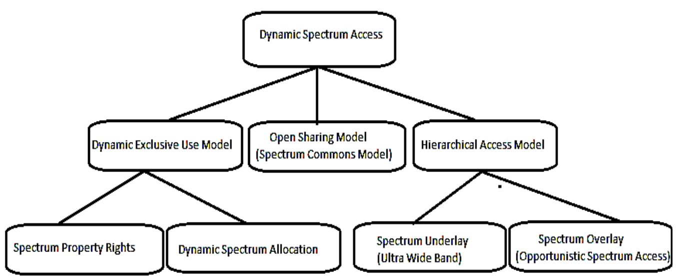

Fig. 4 Taxonomy of DSA

A. INTERFERENCE TEMPERATURE MODEL

Under the Hierarchical category of DSA is the concept of secondary spectrum access which opens licensed bands for unlicensed users (or secondary users SU) to use so long as they do not cause harmful service interruption to the licensed users (also referred to as primary users PU). Three forms of secondary spectrum access have been investigated; interweave, overlay and underlay. In the overlay approach, the SU co-exists over the licensed bands simultaneously without any restriction on its transmitter power but rather on the amount of interference it causes at the primary receiver. This is based on the interference temperature model introduced by FCC in 2002. However, the implementation of this idea in existing literatures is by deploying independently located unlicensed users to co-exist with the existing licensed users. Examples of such deployment are seen in [6]. These implementations lead to dead zones or non-uniformities in the coverage area of the primary user as well as that of the unlicensed user. We therefore investigate the appropriate location of the licensed and unlicensed user BTSs together with any required technique to optimize the overlay cognitive technology in exploring the high under-utilized capacities hidden in licensed bands.

2. RELATED WORKS

This thesis considers spectrum sharing of licensed band by simultaneous coexistence (primary and secondary users transmitting and receiving over the same band at the same time) i.e. overlay networks based on interference temperature model as discussed in Theories section

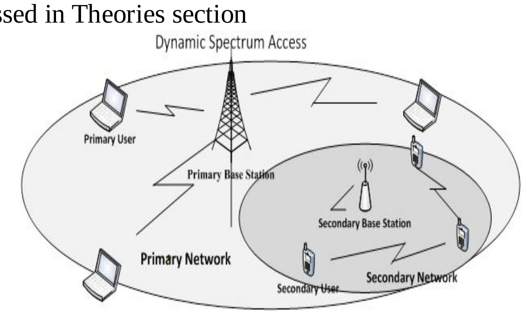

Fig. 5 Spectrum Sharing with DSA

The concept of interference temperature model was introduced by FCC in 2002 [7] and later also in 2003 [8] was to regulate interference based on received power rather than transmitted power. Based on this model, other forms of simultaneous spectrum coexistence have emerged. In [9] an overlay type of secondary access is described where SU co-exist with a primary Digital TV over the TV band (54-862MHz). Two regions of the TV coverage were identified as region of strong primary signal and region of low primary signal and interference temperature was defined for each region. In the region of the strong primary signal power, the interference temperature is given by the local primary signal power (in dB) subtracting the required minimum *SNIR* (in dB). Also in the region of low primary signal power, the interference temperature is specified to guarantee that an interfering signal with the highest allowable power when propagating to the edges of the primary service areas will have a power lower than the noise floor. Similar work was presented in [10] with the SU being a cellular broadband network sharing the TV spectrum with a Digital TV system. In this work, the SU cooperates with the TV system by relaying the TV signals using the cellular network base stations to meet the *SNIR* requirement of the PU and this is done based on prior knowledge of the TV signals and codebook. On the other side, the cellular system uses well known successive interference cancellation techniques and other coding schemes such as dirty paper coding DPC to recover SU signals. *SNIR* at the secondary receivers was shown to improve with the presence of strong TV signals.

The performance of secondary spectrum access based on the interference temperature model has also been discussed in various literatures. In [11], it was found that underlay co-existence based on interference temperature leads to less channel capacity to secondary users except for low data consuming applications. Other studies with similar findings are also presented in [12]. In [10] the channel capacity was estimated in regions of strong primary signal presence.

In all the above literatures, one of the main challenge of overlay network based on interference temperature is the knowledge of the primary receiver location relative to the secondary transmitters as they are deployed at separate locations from the PU transmitters. Near-far end interference situation is created by this arrangement which leads to dead zones or non-uniformities within the coverage area of the PU. Near-Far end interference is the situation where the interfering transmitter is closer to a receiver than otherwise and hence imposes intolerable interference leading to emergence of *coverage dead zones or non-uniformities* for the primary user.

The goal of ensuring limited interference especially in the primary receivers is dependent on the transmit power of the SU and relative distance of the PU receivers from the SU transmitters. Poisson distribution has been used in many literatures to predict the location of secondary transmitter relative to primary receiver. In [6], Poisson distribution was used to estimate the number of secondary transmitters within a certain radius around a primary receiver and the effect of their aggregate interference. Based on this, a new model of exclusive region has been studied in [13] and [14]. An exclusive region is defined as a circular disc centered at a primary receiver with radius *L*. Any secondary terminal within the exclusive region is regarded as harmful interferer and is forbidden to transmit. But the challenge with this solution is how the transmitter is able to determine its location relative to a primary receiver. Three approaches were suggested. First is by making the transmitter sense the RF front end of the primary receiver for RF leakage due to local oscillators but this is limited to short distances. The second is to make the primary receiver transmit beacon signals but this also violates the principle that ensures no modification to the primary user. The third approach is to make the transmitter to sense primary transmitter and predict the presence of primary receivers to be inside the primary service area around the detected primary transmitter, but this approach is also less accurate.

The literature in [15] sought to improve the non-uniformity and the dead zone experienced caused to PU cell by the presence of the SU by cooperation. Under this cooperation, the SU uses part of its transmit power to improve the *SNIR* and coverage of the TV signals by relaying the PU signals using cellular base stations to meet the required *SNIR*.

The other side of this approach is that, since the SU uses part of its power to relay the PU signal, it limits the SU achievable capacity greatly. Again, the SU needs to communicate with the PU network in order to receive and relay its signals. This makes this approach more complex for implementation.

As we have seen, the major challenge of the overlay network based on interference temperature is the Near-Far end interference leading to coverage dead zones around the unlicensed user transmitter (BTS). Some of the literatures discussed above such as [9] [16][13][14] attempted managing the situation but could not eliminate it mainly due to the location of the unlicensed user transmitter or location relative to the licensed user receivers.

In this thesis, we investigate an appropriate location of the secondary transmitter such that the phenomenon of Near-Far end interference and its subsequent *coverage dead zone* as seen in Fig. 6 is eliminated.

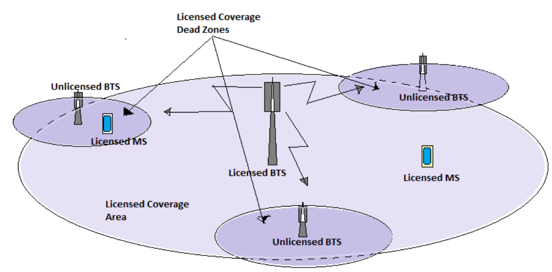

Fig. 6 Dead zones in licensed user coverage due to unlicensed transmitter

In recent times, choice of location of cellular BTSs is being regulated in many parts of the world [17]. In Ghana, the National Communication Authority NCA has a regulation against rampant building of communication mast and demands that co-location is considered as first option in setting up of any new cell sites [18]. This regulation does not favor the approach of deploying secondary spectrum users (and for that matter overlay networks) on separate independent infrastructure in addition to its inherent challenge of causing coverage dead zones or non-uniformities around the SU BTS.

We will also determine any operational or associated technical challenges that may arise out of the choice of the secondary user transmitter location and how they can be managed

3. MOTIVATION

The concept of overlay CR networks based on the interference temperature model was on time to make use of these excess *SNR* to meet other wireless services. Additionally, advances in signal processing and wireless protocols that seeks to ensure reliable communication even over unfavorable wireless channels gives us the space to utilize some of these excess *SNRs* reserved to guarantee certain QoS.

Therefore, optimizing the implementation of the overlay spectrum access based on interference temperature model offers the opportunity to explore under-utilized capacities in regions of high signal presence where normal interweave cognitive radio will not work

4. THEORIES

We briefly highlights the theories and principles upon which this work is based. These are Generalized Signal Propagation Model which is applied to generate signal levels at receivers end and Interference Temperature Model also used to determine amount of interfering signal the PU receivers can tolerate and therefore amount of spectrum power available to the SU transmitter to propagate over the band. Additionally, Shannon Hartley's channel capacity is used to estimate the capacities of the band users

a. SIGNAL PROPAGATION MODEL

Our Analysis and simulations in this chapter are largely based on using the Generalized Signal Propagation Model to generate signal levels, and hence determine *SNIR* and other dependent variables. The model is stated as below [38] in equation (1)

$$R_p = P_t + G_t + G_r - [M(d) + S + L] \quad (1)$$

Where R_p is the received signal power, P_t is the transmitted signal power, G_t, G_r are transmitter and receiver gain respectively, $M(d)$ is the channel path loss in distance d, S is the shadowing effect and L also is the fading loss.

b. SHANNON HARTLEY EQUATION

Shannon-Hartley equation relates the maximum capacity (transmission bit rate) that can be achieved over a given channel with certain noise characteristics and bandwidth. For an AWGN the maximum capacity is given by

$$C = Blog_2(1 + {}^{S}/_{N})$$

Here C is the maximum capacity of the channel in bits/second otherwise called *Shannon's capacity limit* for the given channel, B is the bandwidth of the channel in Hertz, S is the signal power in Watts and N is the noise power, also in Watts. The ratio S/N is called *Signal to Noise Ratio (SNR)***.** For this work, taking into account the interference, the SNR becomes Signal to Noise and Interference Ratio *SNIR*. The channel capacity of both PU and SU are expressed using the Shannon Hartley relation

c. INTERFERENCE TEMPERATURE EQUATION

The interference temperature model is discussed in detail in [48] and is given by equation (2) below

$$T(f_c, B) = \frac{M_h P(f_c, B)}{kB} \quad (2)$$

In our analysis, since we have full knowledge of the primary user signal, we will use the ideal interference temperature model as in [48]. Therefore equation (2) is now expressed as

$$T_{0p}(f_i, B_i) + \frac{M_{hs} P_s(f_i, B_i)}{kB_i} \leq T_L(f_i, B_i) \qquad \forall\, 1 \leq i \leq n$$
(3)

Where $T_{0p}(f_i, B_i)$ is the existing Noise (AWGN) Temperature in the primary receiver circuit for the ith narrowband channel with bandwidth B_i centered at the frequency f_i, $\forall\, 1 \leq i \leq n$, M_{hi} is the signal loss experienced by the signals over the wireless channel in linear scale units. This accounts for the path loss, fading, shadowing effect. We assume an open space with less obstacles hence zero shadowing for the analysis. We also assume the free space path loss model in this case for our analysis which is given by $M_{hs} = (\frac{\lambda}{4\pi d_s})^{\alpha}$, λ is the signal wavelength, d_s is the distance in meters of secondary transmitter from primary narrowband receiver i and α is the path loss attenuation constant given as $2 < \alpha < 4$. But we will use $\alpha = 2$ for this thesis as this is the normally used value. M_{hs} is fractional value typically between 0 and 1.

The expression in (3) is in temperature form, but we wish to express them in terms of the linear signal powers using $P = kTB$ so we can estimate maximum secondary transmitter power to guarantee minimum SNIR at the receiver. We can express equation (3) as;

$$N_{0p}(f_i, B_i) + M_{hs} P_s(f_i, B_i) \leq P_L(f_i, B_i) \quad \forall\, 1 \leq i \leq n \quad (4)$$

Hence maximum interfering SU transmit power is expressed as

$$M_{hs} P_s(f_i, B_i) = P_L(f_i, B_i) - N_{0p}(f_i, B_i) \quad (5)$$

$M_{hs} P_s(f_i, B_i)$ is the interfering signal from the secondary transmissions with power P_s impinged on the ith narrowband primary channel with bandwidth B_i. M_{hs} is the path loss experienced by the secondary signal as it travels from the transmitter to the primary narrowband receiver.

The interference temperature P_L above in equation (5) can be defined in the receiver circuit as the received primary signal minus the minimum Signal to Noise and Interference Ratio

SNIR required for optimum communication in decibel. This is expressed in decibel dB as below

$$\{M_{hi}+P_p(f_i,B_i)\} - SINR = P_L(f_i,B_i) \quad (6)$$

Expressing equation (6) in linear scale i.e. in watts (W) form, we have and combining with equation (5) gives the expression for ITM;

$$N_{0p}(f_i,B_i) + M_{hs}P_s(f_i,B_i) = \frac{M_{hi}P_p(f_i,B_i)}{SINR} \quad (7)$$

$P_L(f_i,B_i)$, the interference temperature limit, is the maximum sum of the Noise and interference due to secondary transmission that still guarantees required *SNIR* at the primary receiver circuit for optimum communication. $M_{hi}P_p(f_i,B_i)$ is the received wanted licensed signal with transmit power of $P_p(f_i,B_i)$ and path loss M_{hi}. $SINR$ is the minimum *SNIR* required to guarantee optimum communication in the primary receiver.

5. METHODOLOGY

The investigation will generally consider two distinct locations of the SU BTS relative to the PU BTS which are;

1. Separately located SU BTS away from the PU BTS
2. Co-location of SU BTS with the PU BTS

In secondary spectrum access, these are probably the two options to choose for the siting of SU BTS and apply the appropriate interference mitigation technique

On each of the above options, we apply below procedure to determine effect on coverage and capacity and hence determine the right location for secondary access.

1. Use Generalized Signal Propagation Model $R_p = P_t + G_t + G_r - [M(d) + S + L]$ together with Free Space Path Loss Model $(\frac{\lambda}{4\pi d_s})^2$ to generate received signal levels (or its expression) at given locations of the Primary user receiver or MS.
2. Estimate the *SNIR* of the PU MS using the relation $SNIR = \frac{Received\ Signal(R_p)}{Noise(N_0)+Interference} \geq SNIR_{minimum}$.
3. $SNIR_{minimum}$ values are used to determine;
   - ✓ Coverage given by $SNIR_{minimum}$ at the edges of the cell.
   - ✓ Channel Capacity using Shannon Hartley's theorem $Capacity = Blog_2(1 + SNIR)$ at the edges of the cell
4. According to the Interference Temperature Model, $Noise(N_0) + Interference \leq T_L$ so as to guarantee the minimum signal to noise and interference ratio $SNIR_{minimum}$ for the PU. Hence we determine the maximum tolerable $Interference$ and subsequently the amount of space (in terms of transmit power) the SU has in sharing the licensed band with the PU
5. We apply an appropriate technique to reduce the effect of the interference leading to enhanced coverage and capacity

The above steps are performed for the two different location of the secondary BTS under consideration and based on their results determine which of them eliminates the coverage dead zones or non-uniformities

a. SIMULATION USING GSM 900 DOWNLINK CHANNEL.

In this section we will apply the theories together with the outlined procedure over the GSM 900 downlink bandwidth of 25MHz (935MHz – 960MHz). This procedure will be implemented in under-listed order of simulation scenarios as follows;

1. GSM user occupying the 935MHz – 960MHz band alone for downlink communication and generate channel capacity and coverage data (and graphs).
2. GSM user co-existing with a separately located (10km apart) unlicensed secondary user transmitting simultaneously (with a given transmit power) over the same band and then generate channel capacity and coverage data (and graphs).
3. GSM user co-existing with an unlicensed user with its BTS co-located with the GSM BTS and generate channel capacity and coverage data (and graphs) using same network parameters as in earlier simulations.
4. Finally, we will introduce spread spectrum in the unlicensed user signals and see how it affects their capacity and coverage together just like in the analysis above.

These data will then be compared to standard operating parameters for GSM and see prospects of such co-existence

All the data which are generated are based on signal level at various locations generated using the Generalized Signal Propagation model. It is used to determine signal levels at given locations when the initial transmit power is given. The signal levels at these given locations are used to determine the Signal to Noise and Interference Ratios *SNIR* and hence a channel capacity using the Shannon Hartley's capacity theory as well as cell coverage.

In starting with this simulation illustration, the operating parameters for GSM 900 is given in Table 3.1 below

Table I. GSM 900 Standard Parameters

Parameter	Standard Values	Units
BTS Transmit Power	42-48	dBm
MS Receiver Sensitivity	-102	dBm
Type of Antenna	directional, 120	degrees
Number of Cells per BTS	3	Cells
Maximum Transceiver per BTS	15 Transceivers	
Maximum Transceiver per Cell	5 Transceivers	
Antenna Gain	15	dBi
Noise Figure	8 for BTS, 10 for MS	
Bandwidth per Channel	200	KHz
Modulation Techniques	GMSK, 8PSK	
Cell Range	35	km
Minimum SNIR	>9 for GMSK, >15 for 8PSK	dB
Maximum Channel Rate	270Kbps for GMSK, 810Kbps for 8PSK	Kbps

From the Table I, we have GSM normal BTS transmit power between 42dBm-48dBm, with a receiver sensitivity of -102dBm at cell edges. Under normal temperature of 293K, the receiver circuit of GSM has noise level of -113dBm, hence this gives a minimum of 9dB SNR for optimum communication.

1) Simulation: From the Generalized Signal Propagation model in equation (1) (equation is slightly modified to include cable loss and interference from other cells) and the GSM Table I

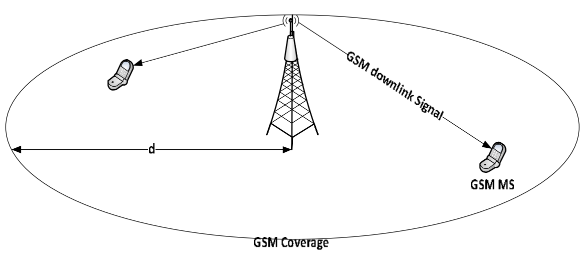

Fig. 7 GSM Cell with no unlicensed interference

$$R_p = P_p + G_t + G_r - [M_{hp}(d) + S + L + C_L + IF]$$

Where R_p is the received signal level, P_p GSM BTS transmit power, G_t is the antenna gain, G_r is the receiver gain, $M_{hp}(d)$ is the path loss based on distance, S is the shadowing loss, L is the fading loss, IF is accounts for other sources of interference and C_L is the cable loss.

Now, given the parameters in Table 1 such as $P_t = 42dBm$, $G_t = 15dBm$, $G_r = 0dBm$, with additional data such as $C_L = 3dB$, $IF = 5dB$ and use $S + L = 30dBm$(which is a typical value in wireless communication). Additionally, we choose a narrowband channel with bandwidth 935.0MHz-935.2MHz (0.2MHz) and center frequency 935.1MHz. The scenario is illustrated in Fig. 7 above.

Simulation scenario I: GSM user alone occupying the licensed band as seen in figure above

Simulation scenario II: GSM user co-existing with a separately located secondary user as seen in figure below over same bandwidth 935.0MHz-935.2MHz (0.2MHz). SU BTS power is considered 40dBm and 10Km away from the GSM BTS

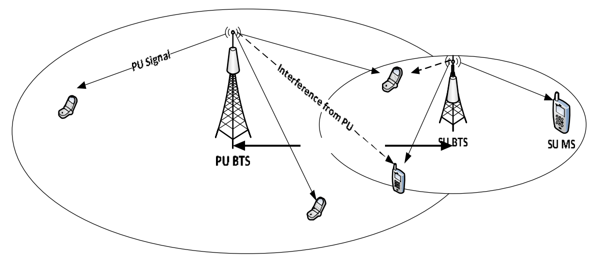

Fig. 8 GSM BTS with separately located (10km) secondary user over the GSM 900 downlink band

Simulation scenario III: GSM user co-existing with a co-located secondary user also seen in figure below over same bandwidth. Same SU BTS power of 40dBm is considered

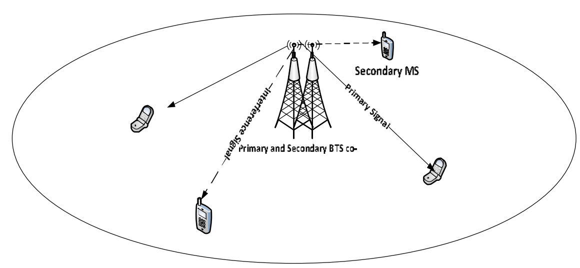

Fig. 9 GSM BTS with co-located secondary user over the GSM 900 downlink band

Simulation scenario IV: Repeating scenario II and III with secondary user signal spread using spread spectrum technology of 20dB gain. Centre frequency of secondary signal is considered as 945.1MHz

Signal levels are generated and plotted using Matlab programming and results shown.

6. RESULTS

b. Scenario I Result

Fig. 10, 11 and 12 show the results for the simulation of GSM 900 downlink band when only the primary GSM downlink user occupies the band. The simulation was done with BTS transmit power of 42dBm, assuming path fading 30dB.

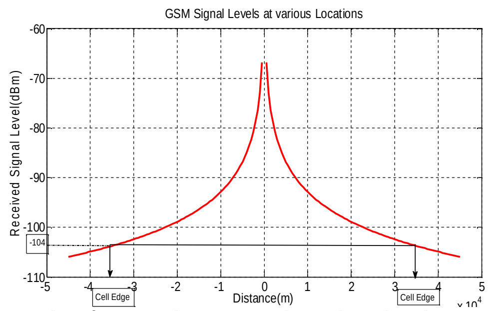

Fig. 10 Results of Received GSM Signal Levels within the coverage area

Fig. 10 shows the distribution of GSM primary user signal distributed over the coverage. It shows that at 35km away from the BTS (which is at location x=0 on the plot) the MS receiver signal is -104dBm which meets the minimum SNR of 9dB at -113dBm noise required for optimum communications at the edges of the cell.

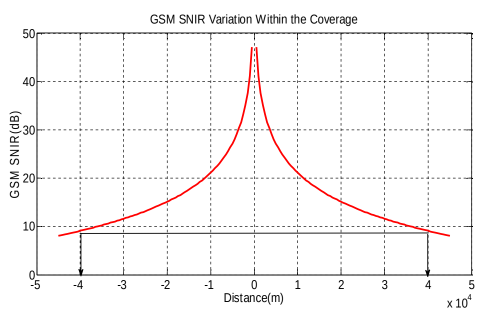

Fig. 11 Results of Signal to Noise and Interference Ratio of the GSM within the coverage area

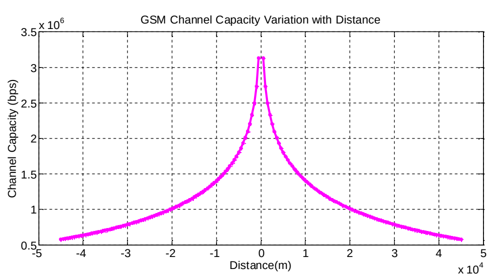

Fig. 12 GSM Channel Capacity distribution within the coverage area

The distribution of the SNR at the MS receiver over the coverage area as seen in Fig. 11 shows that the it is high in the regions closer to the BTS and around 9dB at 35km away from the BTS. The Channel capacity in bps over the coverage shows minimum capacity of 600Kbps at the cell edges 35km away from the BTS as seen in Fig. 12

c. Scenario II Results

The results of the simulation II are shown in Fig. 13, 14 and 15. Fig. 13 shows normal distribution of received signals of both users over the coverage area just like in Fig. 10 in simulation I separated 10km apart, with strong signal power in the regions closer to the BTS but weak at distances away. It is clear from this results that the received signals interfere with each other throughout the coverage area.

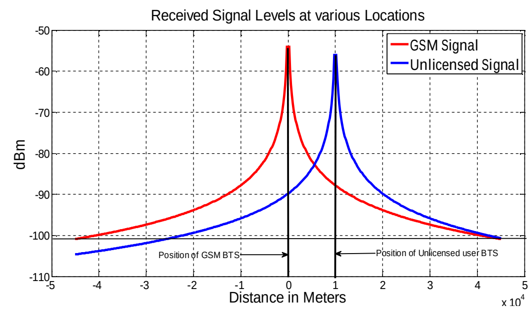

Fig. 13 Results of the Received Signal Levels for both the GSM and Secondary user when separately located

The resulting *SNIR* of the users at the respective receivers is shown Fig. 14. We can see that the interference of each user to the other leads to;

1. Effective coverage area of the GSM (primary user) significantly degraded compared to that in Fig. 10 coverage
2. There is a non-uniform coverage for both the primary and the secondary users around their BTSs. The GSM has coverage radius of 10Km to the left and less than 4Km to the right. Same is seen for the secondary user all due to the far-near end interference phenomenon.

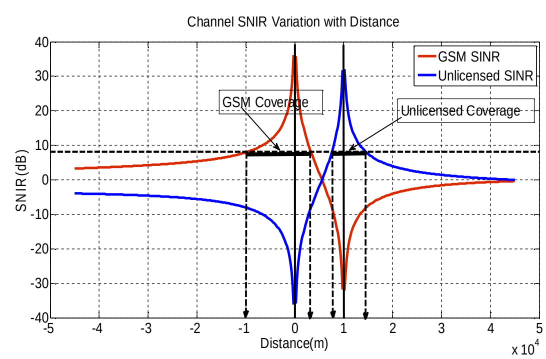

Fig. 14 Results of Receiver SNIR distribution for the GSM and the unlicensed user (separate location)

Lastly, Fig. 15 also shows the distribution of the capacities of both the primary and the secondary user over the coverage area. Again, the result shows that the GSM channel capacity of 600Kbps as seen in Fig. 12 around the edges of the cell is limited to only a small region due to the interference. It can be seen as well in this result that the capacity coverage of both users are skewed in the same order as in Fig. 14

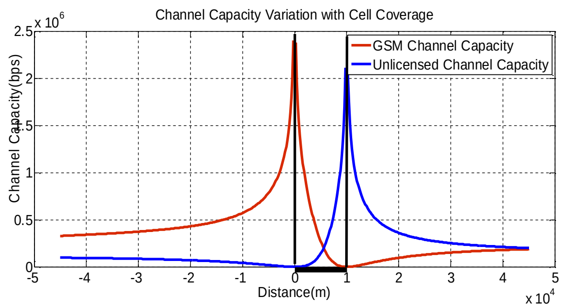

Fig. 15 Results of the channel capacity distribution for the GSM and the unlicensed user (separate location)

d. Scenario III Results

Simulation III result is shown in Fig. 16, 17 and 18. Fig. 16 shows normal distribution of the received signal over the coverage just as in Fig. 10 and 13 discussed earlier, however, their signals interfere with each other just like in the simulation II results.

Fig. 17 and 18 therefore respectively show the resulting *SNIR* and user capacities of each user distributed over the given coverage area. The co-location has given out uniform cell coverage on either side of each BTS, eliminating the undesirable skewed cells. However, keeping the transmit powers employed by the two users as in earlier simulations, we can see from these Figures that the *SNIR* of each user is badly degraded and hardly meets the minimum *SNIR* for effective communication. The co-location therefore leads to;

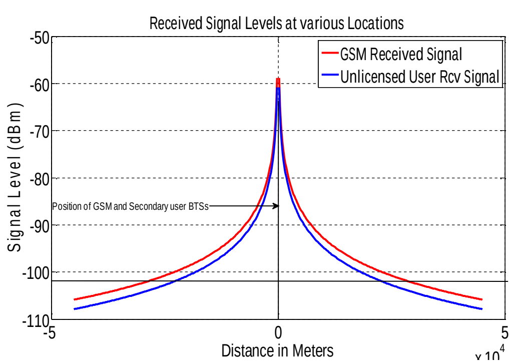

Fig. 16 Results of Received Signal Level for both GSM and secondary user when they co-located

1. Elimination of the skewing as seen in the separate location of BTSs. This is desirable achievement for the uniformity of the GSM cell as well as the secondary user cell.
2. However, the coverage of each user is badly degraded even below minimum *SNIR* for effective communication due to extreme interference having both BTS to co-locate
3. The degraded *SNIR* also leads to poor capacity.

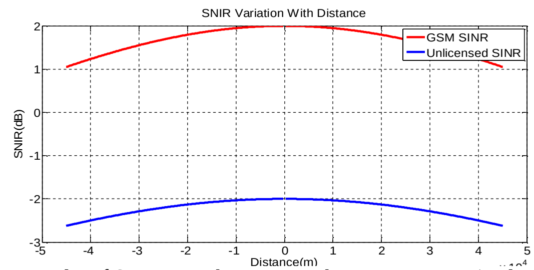

Fig. 17 Results of SNIR Distribution over the coverage area (co-location)

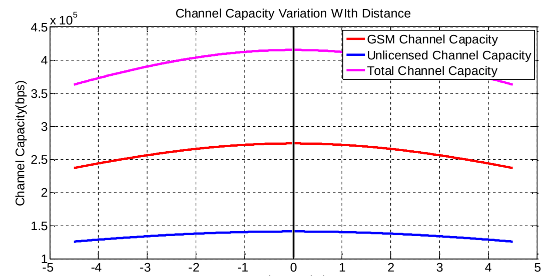

Fig. 18 Results of channel capacity distribution over the coverage area (co-location)

e. SIMULATION IV RESULTS

The last simulation results is seen in Fig. 19, 20, 21 and 22. In this simulation result set, both scenarios of separate location and co-location of BTS were simulated. However, in these instances, the secondary spectrum user was made to spread its signals using spread spectrum technology by 20dB of the original baseband signal i.e. spreads every data bit by 100 chips before transmitting.

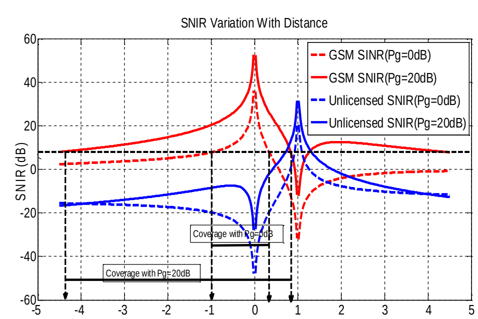

Fig. 19 Results of SNIR distribution for separate location of cell sites when unlicensed user signal is spread over wide band

Fig. 19 and 20 show results for the separate location of the user BTSs. We can see from these two results that, the spreading of the secondary spectrum user leads to reduced interference on both users and hence improved *SNIR* which leads to improved coverage and capacity for both users.

The coverage of the GSM user has improved significantly on one side of the BTS to almost its original coverage in Fig. 10. We can also see that the secondary user has also seen significant improvement in coverage and capacity on the side of the BTS far from the GSM BTS. However, the undesirable problem of skewing is still present leading to a non-uniform cell coverage for both users.

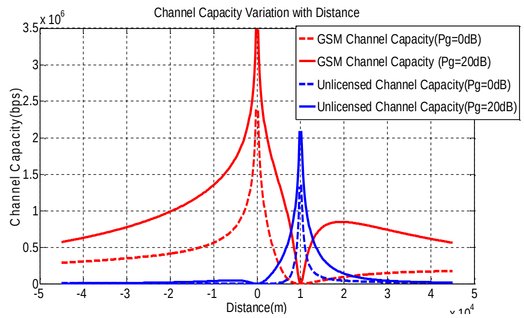

Fig. 20 Results of Channel capacity distribution for separate location of cell sites when unlicensed user signal is spread over wide band

Fig. 21 and 22 also show the result for the case when both the primary and the secondary spectrum user BTSs were co-located. Again, the secondary user used spread spectrum technology to spread out its signals over the wireless channel.

Just the same way as in the results in Fig. 19 and 20, the spread spectrum led to a reduced interference on both users. This in turn led to improved coverage and capacity when the transmit power of both transmitters were kept the same. The GSM graphs in these figures clearly shows almost just like in Fig. 10, 11 and 12 when there was no secondary user interference. This is the enhancement achieved by the introduction of the spread spectrum technology together with the co-location. Moreover, the secondary user has also improved in both coverage and capacity although still not enough for effective communication. However, if it is viewed from the point of a secondary user that is only allowed a piece-meal of the licensed band to meet some small coverage and capacity communication need, then this can be considered as milestone. The skewing of cell is also eliminated by the co-location.

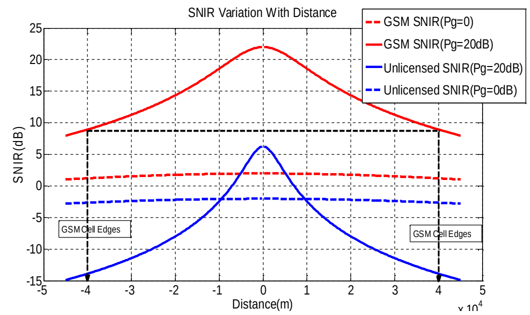

Fig. 21 Results of SNIR distribution for co-location of cell sites when unlicensed user signal is spread over a wider band

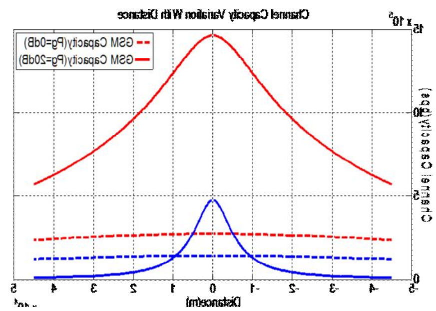

Fig. 22 Results of channel capacity distribution for co-location of cell sites when unlicensed user signal is spread over wide band

f. FURTHER OBSERVATIONS.

Moreover, this co-existence can further be manipulated depending on how much of secondary capacity is required and how much of degradation is allowed on the primary user. For cases of primary user where their capacities are greatly under-utilized, we can afford to subject it to more degradation for the purpose of releasing capacity to the secondary user. This manipulation can be achieved by manipulating the SU transmitter power together with the spreading

Fig. 23 and 24 show example of this manipulation, when the secondary transmit power increased to 54dBm and spreading at 25dB whilst keeping the GSM at 42dBm. We can observe Fig. 23 that GSM coverage is maintained, however under-utilized capacity around the GSM BTS area is released to the SU.

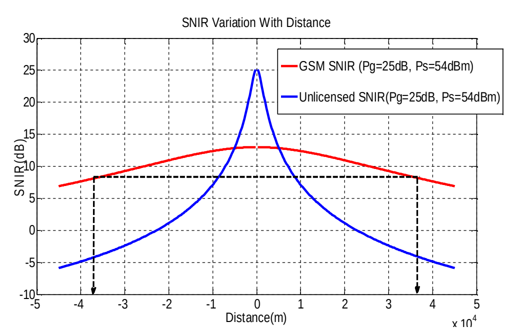

Fig. 23 Improved unlicensed SNIR for co-location when processing gain and unlicensed transmit power is increased to 54dBm

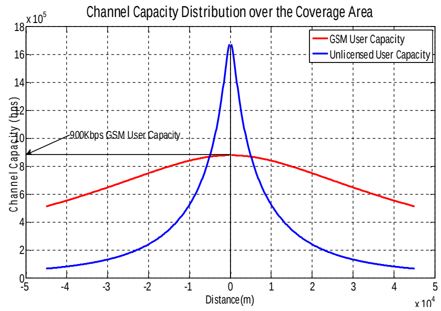

Fig. 24 Channel Capacity sharing for co-location when processing gain and unlicensed transmit power is increased to 54dBm

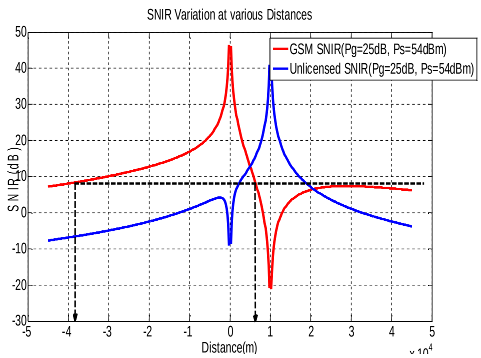

Fig. 25 Slight improvement of unlicensed SNIR for separate location when processing gain and transmit power is increased

7.CONCLUSION

Based on the analysis where generalized signal propagation model was used together with interference temperature to derive coverage and capacity expression with the results from the simulation confirming them, we make the following conclusion;

Co-locating unlicensed user SU BTS with that of the licensed user PU BTS is the appropriate location for the elimination of coverage dead zones or non-uniformities in secondary spectrum access based on interference temperature model

However, this leads to very high service degrading interference to the licensed user. This violates the principles of secondary spectrum access which demands the presence of the unlicensed user do not cause any service disruption to the licensed user.

Spread spectrum technique (either frequency hopping or direct sequence) used to spread the unlicensed user signal over a wider band reduces the effect of the interference significantly. This makes it possible to open up the licensed band for the under-utilized power resources to be used to meet other communication demands

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