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Improving quality of service in Worldwide Interoperability for Microwave Access networks using spectrum-sharing technique

Abstract. There is a huge demand for data as subscribers are becoming very familiar with mobile devices and its applications. A huge amount of data is being transmitted and received as this communication goes on. It is imperative that with the limited resources available to the network operators, the spectrum through which all these data is used is managed efficiently. This has brought about the need for network providers to combine their resources to furthermore provide a better quality of service to subscribers. Sharing the spectrum in which they operate is one way of solving this problem. In this study, we consider the benefits of sharing a redundant spectrum bought by two network providers who have come in an agreement to use it judicially when it becomes necessary. The parameter used for the analysis are throughput and blocking probability. A comparison is done using these two parameters with respect to the direct link and the spectrum shared link. In our findings, the spectrum sharing scenario proposed, was really efficient when facing issues with blocking probability and throughput by given an optimum of 0.0501 and 21.4Mbps respectively at 20% traffic load, thus increasing the quality of service of the system. This shows how better off it would be for network operators to share their resources as it provides a better quality of service to the subscribers.

Keywords: WiMAX; spectrum; blocking probability; throughput; shadowing losses; power and bandwidth.

I. Introduction

A. Spectrum sharing

Spectrum sharing can be said to be a systematic approach of using the same frequency spectrum by network operators either by regulation or by mutual agreement. There are two basic categories of spectrum usage: exclusive usage based on some form of spectrum property rights and non-exclusive usage based on either licensing particular types of usage or classes of users – e.g. public mobile radio – or based on exempting spectrum from licensing – e.g. the 2.4 GHz bands used by Wi-Fi and Bluetooth. The term RF spectrum refers to that portion of the electromagnetic continuum that is subject to some form of regulated use. At its lower end, this range includes the Ultra-Low Frequencies (a few kilohertz) used for communications that span the globe and penetrate earth’s (watery) surface. Its higher end reaches into the submillimeter waves that correspond to frequencies of 300 GHz and more.

There are different types of spectrum allocations: primary allocations and secondary allocations. These allocations are made to “services” e.g. the mobile service or the radiolocation service. The primary allocation affords the incumbent service protection against interference from a service with secondary status. Use of the radio spectrum has caused enormous changes in the ways people and organizations communicate, conduct their business and entertain themselves. Because of the apparently limitless propagation of radio waves, early spectrum “decisions” focused on separating different types of usages and different groups of users. With the emergence of new types of use and the increasing importance of new applications such as the remote control, scientific observation, notably radio astronomy, telemetry, etc., the usable spectrum rapidly filled up. Given the demands for ever more bandwidth by a growing number of applications, it is understandable that some think there is a spectrum scarcity that needs extreme measures to address.

However, practice is different. Although there is significant asymmetry between the government controlled spectrum and “civilian” spectrum, there is no scarcity as such. There is, however, a strong desire on the part of many players in this field to crowd together in the most attractive spectrum range – between 30 and 3,000 MHz. In this frequency range, propagation is generally good and the achievable bandwidth adequate for most purposes. Therefore, usage of this spectrum has to be shared in some way. Some, like Calabrese and Benker [1] argue that advancing technology– exemplified by Cognitive Radio – will make it possible to share all of this spectrum without prior arrangements. Not only vested interests but also theory and practice suggest that these attractive visions are not realizable. The problem of spectrum sharing is first and foremost a technical problem, the of effective channel throughput and the fact that the environment, even in the solutions of which are bounded by the Shannon-Hartley theorem of effective channel throughput and the fact that the environment, even in the desert or at sea, confronts us with propagation conditions that change with location, time of day, the weather, etc

B. The future of spectrum sharing

The way forward in spectrum sharing can be looked at from the perspective of the user, regulator and industry. For the sake of this study, the researcher will look at it from the view of the industry. The wireless industry has developed and implemented many schemes of spectrum sharing, ranging from the tight in-band and out-of-band emission limits and block edge masks of the cellular industry to the carrier sense multiple access scheme of wireless LANs. All of these schemes focus on optimizing the system itself rather than aiming at generic spectrum sharing. Such a policy makes sense, given that the current radio regulations are selective rather than inclusive. However, in this study a different approach is proposed in which redundant spectra would be put to use when one operators network is congested. [2]

C. Spectrum Sharing in WiMAX networks

In Wimax systems a number of uncoordinated coexistence mechanisms can be implemented

Upon system start-up, the base station (BS) shall choose a suitable channel in which to operate. Channel selection shall depend upon the requirements for operation in a given band. If the band contains *specific spectrum user*s (SSUs), the BS shall use a protocol termed dynamic frequency selection "DFS" to attempt to find a channel free of SSUs. If the band contains only non-SSUs (IEEE 802.16 or non-IEEE 802.16), the BS uses the dynamic channel selection (DCS) protocol to find the best channel for operation. In certain regulatory regimes where SSUs are not present, it may be sufficient for the choice of channel to be able to be performed manually with coordination between operators as needed. If the band contains both SSUs and non-SSUs (IEEE 802.16 or non-IEEE 802.16) then both DFS and DCS protocols are used together. The DFS protocol is used to avoid interference to SSUs by vacating the channels on which SSUs are detected, and additionally DCS is used to select the best channel of the set of channels in the band that are cleared for operation by DFS.

The BS shall continue to perform DFS and DCS operation, as required, selecting the most appropriate channels based on the prevailing conditions and reacting to reported measurements from the SSs. [3]

II. Related Works

A dynamic spectrum sharing approach using hierarchical co-channel macro and pico cells is proposed in [4], that proves the feasibility of spectrum sharing. A roadmap for evolution towards dynamic spectrum sharing is introduced. Three basic models of spectrum sharing exist as at now: public commons, private commons and the exclusive transmit rights models. Public and private commons models are based on the co-channel sharing spectrum among multiple parties. However, the exclusive transmit rights and coordinated access describes the dynamic allocation of non-overlapping blocks of spectrum as administered by a spectrum broker. Here a coordinated access band is reserved for controlled dynamic access. Different operators use the coordinated access bandwidth (CAB) when required. After a quick overview of the three models proposed, a case scenario involving hierarchical co-channel macro and pico was the most appropriate for spectrum sharing in cellular networks. Review [5] proposes a solution to the problem of sharing spectrum. Their approach was basically based on game theory. Indeed, they looked at spectrum sharing in cognitive radio network where the primary user is allocated a licensed radio spectrum and the utilization of which could be improved by sharing it with secondary users; they considered the problem of spectrum sharing among a primary user and multiple secondary users. They formulated the problem as an oligopoly meaning few internet service providers (ISPs) could control and distribute the spectrum to multiple secondary users as well as controlling the pricing.

The method they used to allocate spectrum for secondary users was non-cooperative game theory where users' make decisions independently. The main objective of using non-cooperative game theory was to maximize the profit of all secondary users based on the equilibrium adopted by the secondary users.

Reviews [6] [7] [8] looked at the possibility of dynamically assigning frequency spectrum from a wide area network provider such as WiMAX to a wireless local area network such as Wi-Fi. In [6] the researcher looks at two cases of spectrum sharing: i) when the network providers are cooperative. In this case, spectrum sharing can be done easily and that improves user throughput on the average and ii) when the providers are not cooperative. In that case they introduce a threshold to assign an additional channel from a WiMAX base station (BS) to Wi-Fi access points (APs). Review [7] also proposes a spectrum sharing method even if WiMAX/Wi-Fi operators are uncooperative. They introduce satisfaction as an indicator of a users' behaviour. In this article, the scenario used is when operators are willing to cooperate.

Most of the literature on spectrum sharing to improve quality of service concentrates on heterogeneous networks. However, in this article we introduce a novelty idea of sharing spectrum by homogenous network using WiMAX as our model network. Throughput and blocking probability are used as determining factors. In this era of data intensive multimedia applications and scarce bandwidth, this proposed method will help improve on the quality of service of the network.

III. Proposed Method

In this section, we propose a spectrum-sharing model between two service providers. It is assumed the service providers have a mutually beneficial arrangement to share spectra (i.e. a kind of roaming agreement). The reserved spectra will be shared under these conditions:

a) When the user equipment is trying to communicate with the home basestation (BS) and encounters a poor quality of service network, which cannot offer an effective transmission [9] as in fig 1. (In the case of fig 1. there is an obstruction which might be fading the channel so the user equipment can be switched to use the reserved bandwidth from the algo BS which might not be fading)

b) When the network of one operator is congested as seen in fig 2, traffic can be routed through the other network (in our case the algo BS) to reduce the blocking probability of the network.

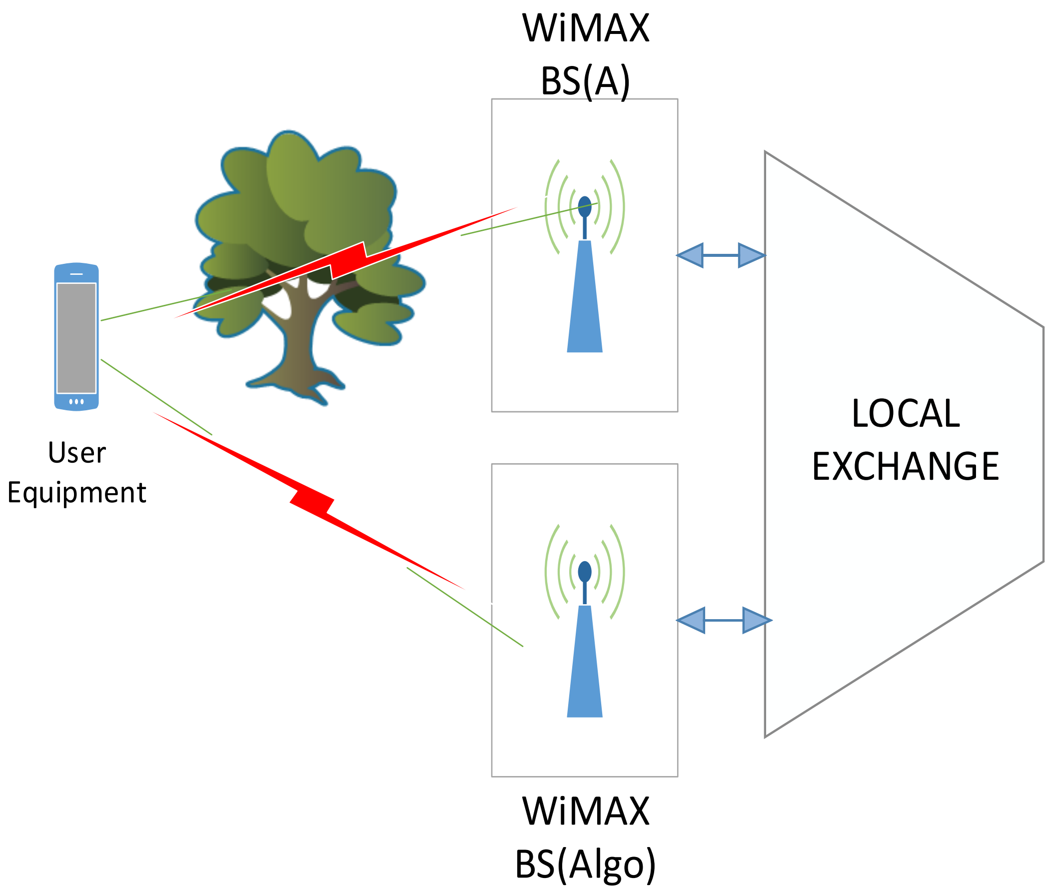

Fig. 1. *Spectrum sharing because of low throughput*

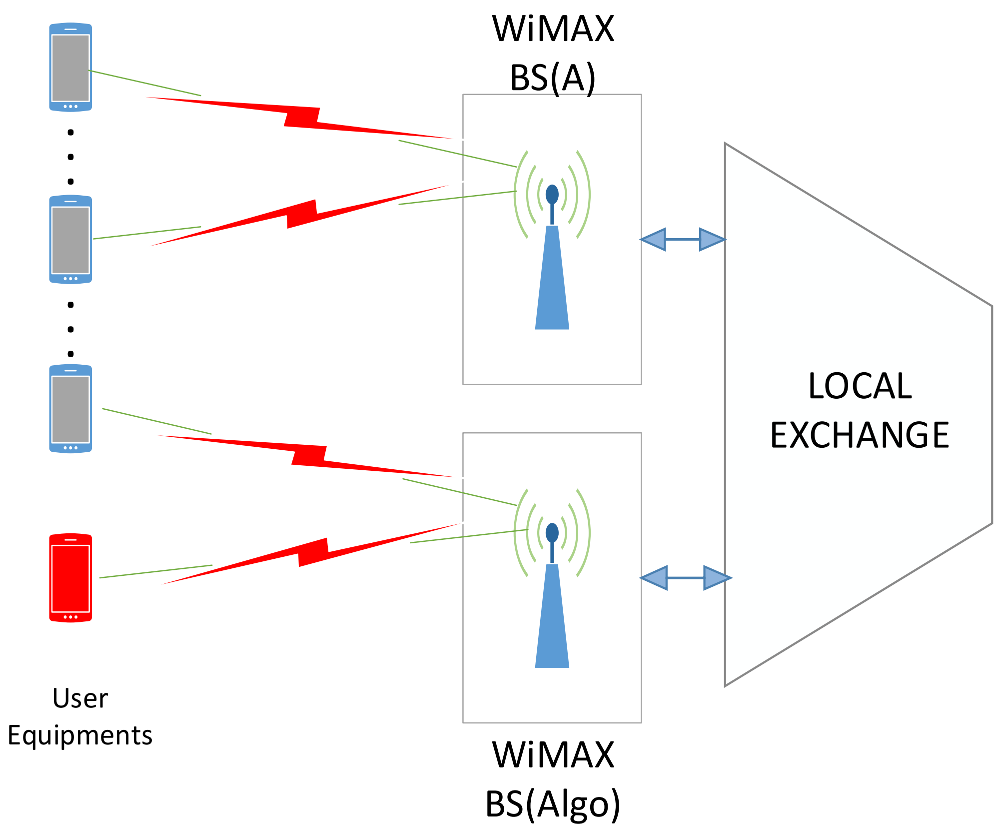

***Fig. 2.** Spectrum sharing because of congestion*

A. Flowchart of spectrum sharing

In the spectrum sharing scenario, it is assumed that the spectrum resources to achieve the quality of service for a given transmission are not met. A threshold of 0.7 for the blocking probability is set up. The network's blocking probability is then evaluated and compared to the predefined blocking probability threshold as shown in fig 3. In case the blocking probability value is less or equal to the threshold, transmission occurs using the network own resources. On the other hand, when the blocking probability is greater than the threshold then transmission is routed through the algo link. For the purpose of this research the algo link is modelled in a way that there will always be free spectra to share with network A

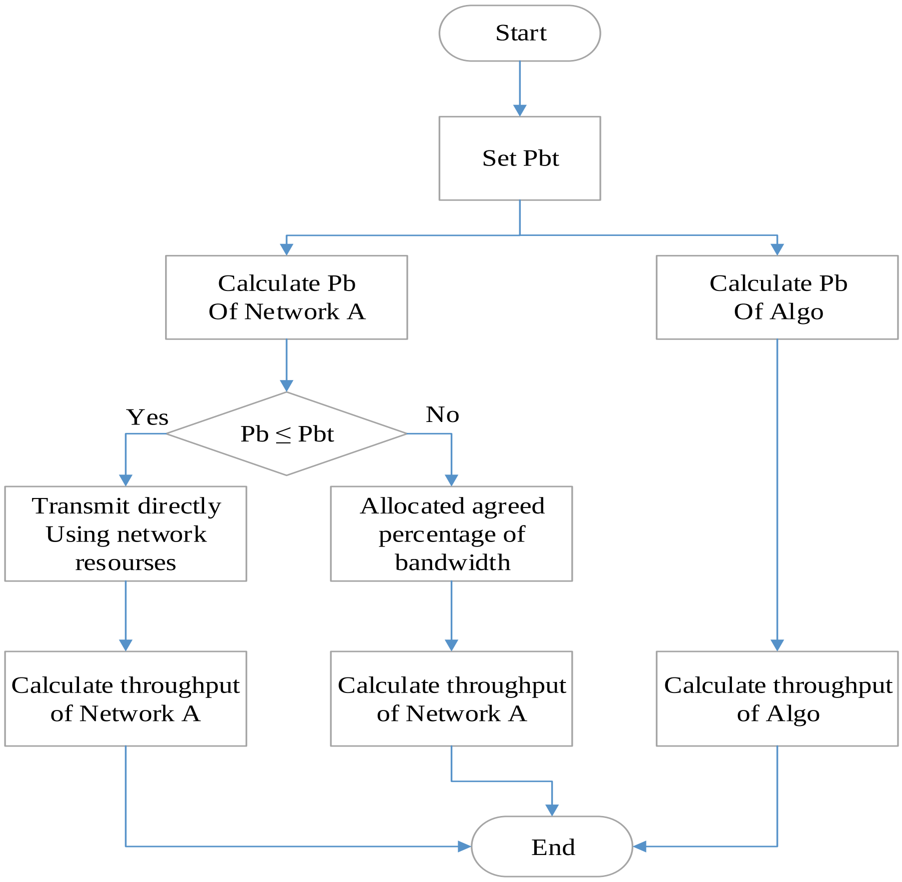

Fig 3. *Flowchart for spectrum sharing approach*

Pbt is the call blocking probability threshold

Pb is the call blocking probabilty.

B. Metrics used

a) Power

The received power is evaluated by the formula:

$P_r = \boldsymbol{P_t} \cdot \boldsymbol{K} \cdot \boldsymbol{r}^{-\eta} \cdot \boldsymbol{X} \cdot \boldsymbol{Y}$ (1) [10]

Where:

P_r is the received power by the Base station

P_t is the transmitted power by UE

X is the Fading effect along the path of UE and BS

Y is the Shadowing effect along the path of UE and BS

R is the distance between UE and BS

η is the path loss exponent

K is a constant

b) Path loss

Path loss is the reduction in power density of an electromagnetic wave as it propagates through space. Path loss is a major component in the analysis and design of the link budget of a telecommunication system. This term is commonly used in wireless communications and signal propagation. Path loss may be due to many effects, such as free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss, and absorption.

- Path loss exponent

In the study of wireless communications, path loss can be represented by the path loss exponent values in the range of 2 to 5 [11]. Since we working in a suburban environment, the value 5 will be used as our path loss exponent. Table 1 shows different path loss values for various environment

Table 1

Path loss exponent with their corresponding environment

ENVIRONMENT	PATH LOSS EXPONENT Y
FREE SPACE	2
URBAN AREA	2.7 TO 3.5
SUBURBAN AREA	3 TO 5
INDOOR	1.6 TO 1.8

c) Power received

In all communications systems there is a minimum power to be received so that modulation or demodulation and processing of the signal can be done. It is the smallest signal power that can be received, processed and demodulated by the receiver [10].

This minimum threshold depends upon the type of information transmitted and the technology being used. The power received by a base station from the user equipment (UE) depends on the radio channel conditions and varies with time due to fading effects caused by multi-path reflections and shadowing. [12]

d) Power transmitted

A typical WiMAX base station transmits at power levels of approximately +43dBm (20W), while the user equipment typically transmits at +23dBm (200mW). There is a large difference between downlink and uplink power, so while a user equipment can receive transmission from a base station, the mobiles relatively low transmit power makes it difficult for the base station to hear it. As the mobile moves closer to the base station, path loss decreases. The signal level at the base station decreases and SNR improves. In response, the base station instructs the mobile to start reducing power.

It follows from equation (1) that the transmitted power by UE is given as:

$$P_t = \frac{\boldsymbol{P_r}}{\boldsymbol{K \cdot r^{-\eta} \cdot X \cdot Y}} \qquad (2)$$

We derived $\mathbf{P_t}$ in dB as:

$$P_t[dB] = 10 \cdot log\left(\frac{P_r}{K \cdot r^{-\eta} \cdot X \cdot Y}\right) \qquad (3)$$

$$P_t[dB] \ = 10 \cdot \log(P_r) - 10 \cdot \log(K \cdot r^{-\eta} \cdot X \cdot Y)$$

$$= 10 \cdot \log(P_r) - 10 \cdot \log(K) - 10 \cdot \log(r^{-\eta}) - 10 \cdot \log(X) - 10 \cdot \log(Y)$$

$$P_t[dB] = 10 \cdot \log(P_r) - 10 \cdot \log(K) + 10 \cdot \eta \cdot \log(r) - 10 \cdot \log(X) - 10 \cdot \log(Y) \qquad (4)$$

This equation is illustrated by the following the fig 4 which shows the inputs as the variables that help to calculate our output and the transmitted power.

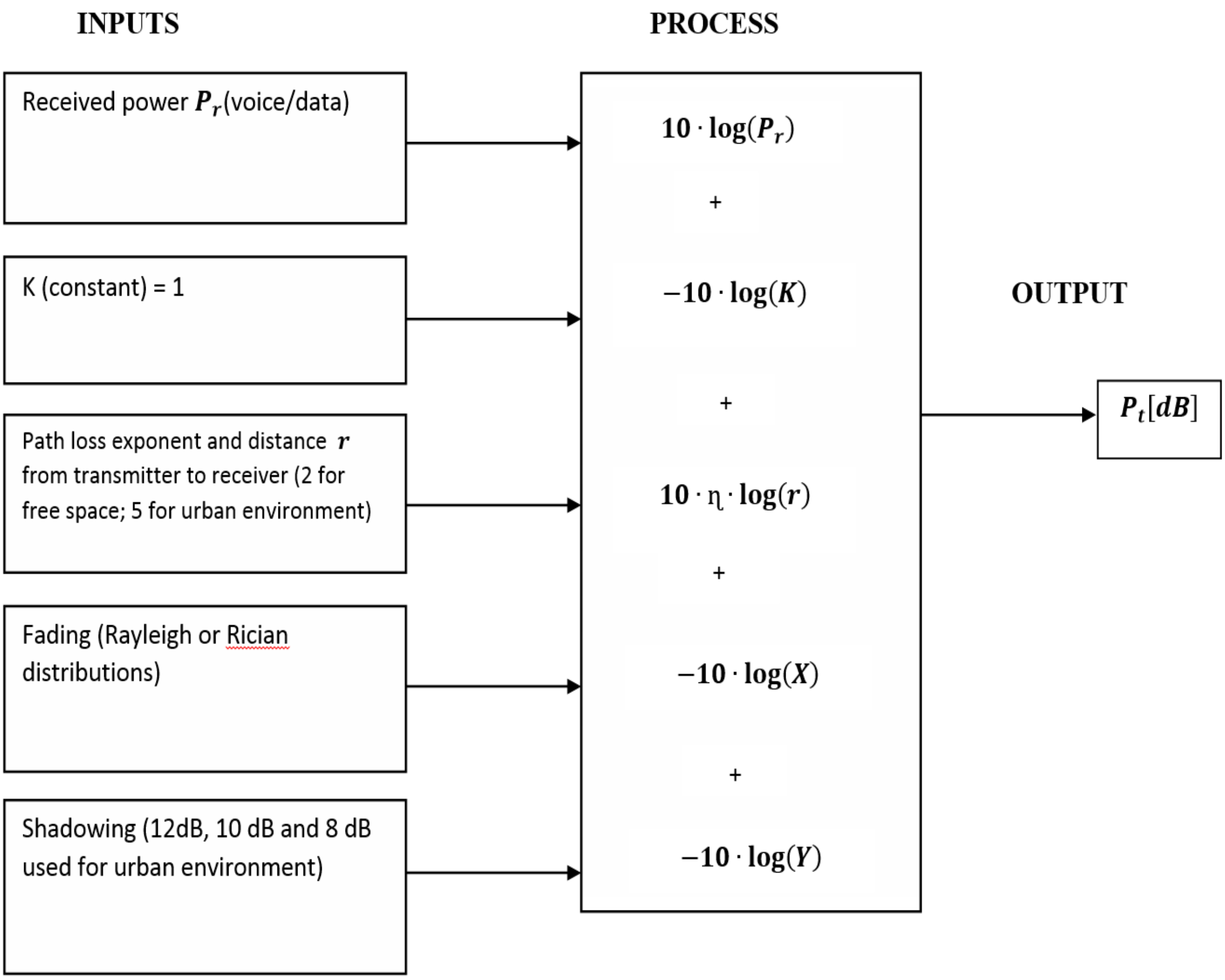

Fig 4. *Breakdown of input to output process*

e) Shadowing losses

These losses occur due to physical obstacles such as buildings that block the signals and causes attenuation. It is also known as Long Term Fading. It is mostly defined as 12db for urban areas [9]. A signal transmitted through a wireless channel will typically experience random variation due to blockage from objects in the signal path, giving rise to random variations of the received power at a given distance. Such variations are also caused by changes in reflecting surfaces and scattering objects. The location, size and dielectric properties of the blocking objects as well as the changes in reflecting surfaces and scattering objects that cause the random attenuation are generally unknown. Thus statistical model must be used to characterize this attenuation. The most common model for this additional attenuation is log-normal shadowing. For urban environment, the shadowing value commonly used is 12dB. [13]

f) Throughput

The throughput is a measure of how fast we can actually send data through a network.

Although, at first glance, bandwidth in bits per second and throughput seem the same, they are different. A link may have a bandwidth of B bps, but we can only send T bps through this link with T always less than B. In other words, the bandwidth is a potential measurement of a link; the throughput is an actual measurement of how fast we can send data. In wireless networks, the system spectral efficiency in bits/ hz cell is the maximum system throughput divided by the analogue bandwidth and some measure of the system coverage area. The throughput in communications measures the amount of raw bytes sent by a source.

For wireless systems, all the effects associated with wireless transmission limits the signal to noise ratio (SNR) and bandwidth of the received signal, therefore the maximum number of bits that can be sent. [14]

Throughput can be expressed by the formula below:

$$Th= BW \cdot \log_2 (1+SNR) \quad (5)$$

Where,

$SNR= \frac{S}{N}$ (6)

BW is bandwidth

S is signal power

N is noise power

g) Blocking probability

New wireless communications networks design is based on a cellular architecture. In each cell, a set of channels is allocated to each base station. Neighbouring cells have to use different channels in order to avoid intolerable interferences. When a mobile user wants to communicate with another user or a base station, it must first obtain a channel from one of the base stations that hears it (usually, it will be the base station which hears it the best). If a channel is available, it is granted to the user. In the case that all the channels are busy, the new call is blocked. This kind of blocking is called new call blocking and it refers to blocking of new calls. The user releases the channel under one of the following scenarios: the user completes the call or the user moves to another cell before the call is completed. [9]

The fraction of blocked arrivals in the long run of the system is called the blocking probability (bp). Blocking probability is a quantity really important since it is used to define Quality of Service in cellular networks. It can be defined using Erlang's loss formula: bp is equal to the conditional probability that in the stationary configuration of the (non-blocked) arrival process the system cannot admit a new user, given all users in the current configuration can be served.

Blocking probability can be defined by the following formula:

$$bp= \frac{(\frac{A}{N!})^N}{\sum_{i=0}^{i=N}\left((\frac{A}{i!})^i\right)} \quad (7)$$

Where,

A: Traffic Load

N: Number of Channels

IV. Results and Analysis

The proposed model is simulated in Matlab 2012 version using the metrics described above. The quality of service of a system is measured by evaluating the grade of service or the blocking probability of the transmitted traffic. Considering the developed algorithm, the system's grade of service is evaluated with regards to the traffic load and the available channels.

The spectrum sharing approach is used and has been implemented as follows. Firstly, an assumption was made that the two service providers have a percentage spectrum to be shared at any point in time when the threshold of the blocking probability of any of them is not met. The operator then, can forward some of its traffics through the common shared spectrum.

A. Results showing blocking probability evaluation in the algo link and the spectrum sharing link

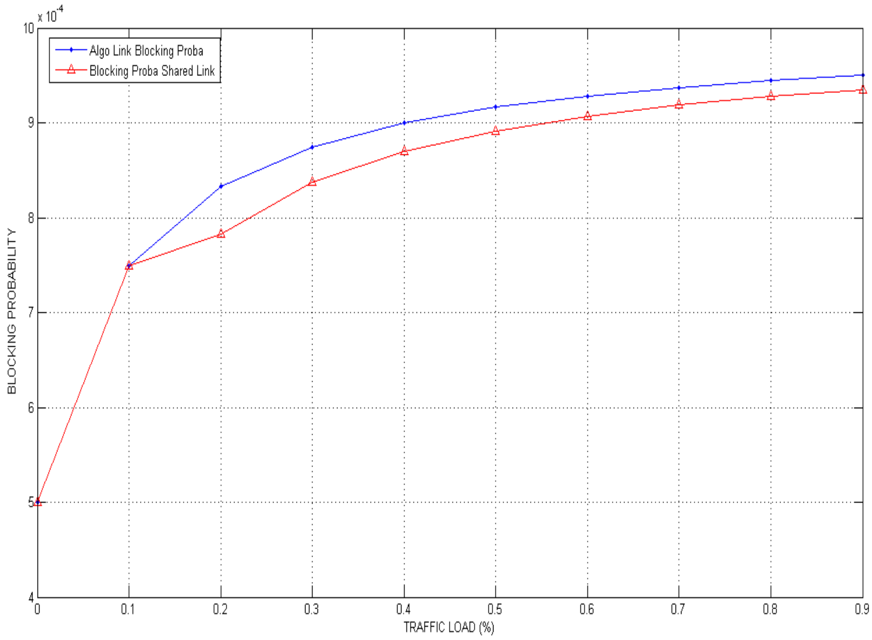

Fig 5. *Results of blocking probability algorithm*

From fig 5. it can be observed that up to 0.1 % increment of the traffic both scenarios offer the same blocking probability, this because both scenarios are using the same resources. As the traffic load increases, it can be observed that network A starts using the shared spectra so the blocking probability reduces compare to the algo link. However, the blocking probability increases for both algo link and spectrum sharing scenarios.

B. Results showing the throughput evaluation for direct, algo and spectrum sharing links

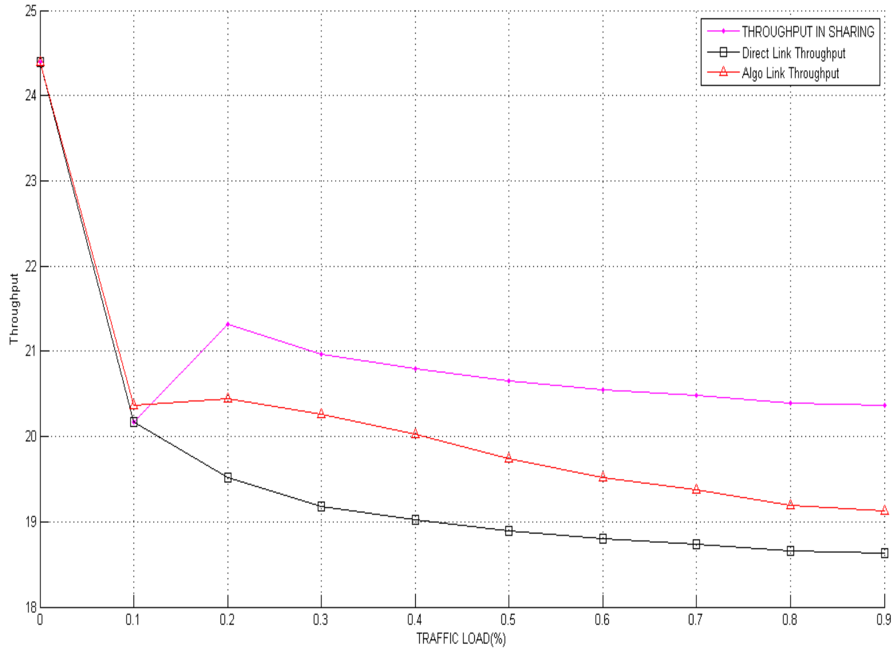

Fig 6. *Results of throughput evaluation for direct, algo and spectrum sharing links*

As shown in fig. 6, up to 0.1 % of the traffic load, the throughput of the system when the algo algorithm and that of the direct link (i.e the user equipment communicating directly with its own basestation in the face of obstruction) throughput, are similar. Conversely, when considering the spectrum-sharing platform it was noticed that the system throughput is the same. This is because during that period the normal direct link system resources are being used. However when the traffic load increases, it is noticed that there is a variation in the behaviour of the system throughput as far as algo, direct and Spectrum sharing scenario are concerned. Between 0.2 and 0.3 increment in the traffic load it is noticed that, there is a raise in the throughput of the spectrum-sharing scenario. This is because the system starts using the shared bandwidth. As traffic keep increasing the system throughput decreases relatively faster for the direct link as compared to the algo and spectrum sharing scenarios. However the shared spectrum scenario offers a better throughput among all others. From 0.8% increment in the traffic load, it is observed that the throughput of the spectrum-sharing scenario is stabilized while the throughput of the algo link is still decreasing.

C. Results showing the impact of the variation in percentage of the spectrum utilized

Since spectrum sharing offers better blocking probability and better throughput it is imperative to know how the variation in size of the additional shared spectrum impacts on the system.

For throughput variable, the shared spectrum size has been varied. We have considered three scenarios of spectrum sharing.

Sharing: the service provider uses 75% of the shared spectrum

Sharing 1: the service provider uses 50% of the shared spectrum

Sharing 2: the service provider uses 30% of the shared spectrum

The graph bellows shows the results obtained.

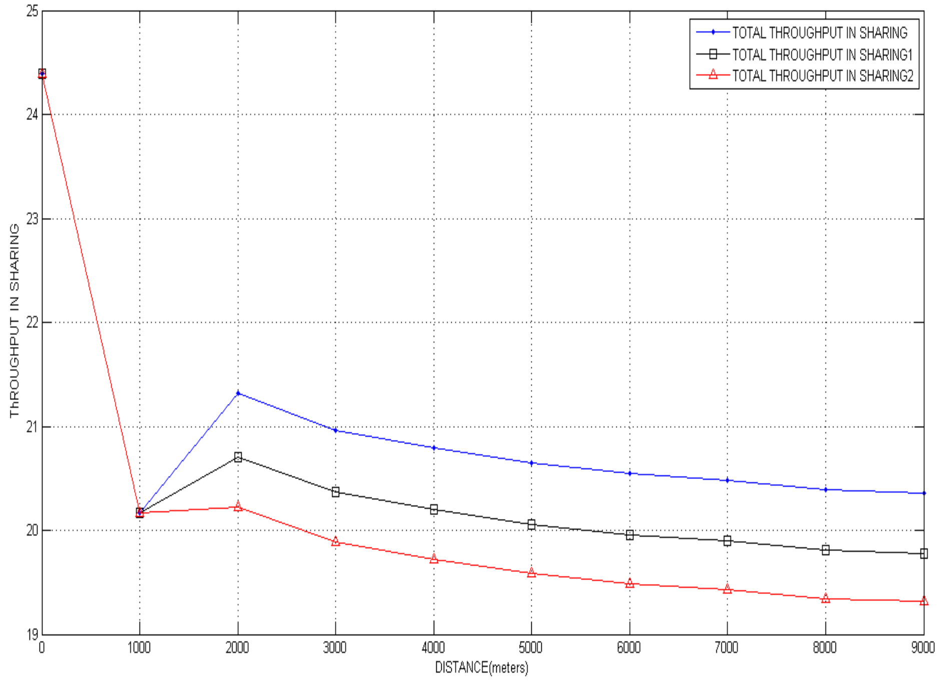

Fig 7. *Results showing throughput in varied shared spectrum sizes*

From fig. 7, sharing offers a better throughput than sharing 1, which also offers a better throughput than sharing 2. Therefore we can conclude that the bigger the bandwidth available for utilization in the spectrum sharing scenario, the better the efficiency of the system.

Here also, up to 0.1 % of the traffic load the throughput is decreasing because the system uses only its available resources. The raise observed indicates that some bandwidth has been added to the original system resources and the decrease in the different throughput graphs is explained by the continuous increment in traffic load.

V. CONCLUSION

The spectrum-sharing scenario proposed, was efficient when facing issues with blocking probability and throughput by given an optimum of 0.0501 and 21.4Mbps respectively at 20% traffic load, thus increasing the quality of service of the system.

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Повышение качества обслуживания в сетях WiMAX на основе совместного использования спектра

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Аннотация. В настоящее время по мере того, как абоненты знакомятся с возможностями мобильных устройств и преимуществами, предоставляемыми современными сетевыми приложениями, увеличивается спрос на услуги обмена данными. В связи с этим возрастают требования к системам связи по объемам передаваемого и принимаемого трафика. С ограниченными ресурсами, доступными сетевым операторам, важно, чтобы спектр, посредством которого все эти данные передаются, управлялся бы максимально эффективно. Данная статья посвящена улучшению качества обслуживания в сетях WiMAX, основанному на совместном использовании определенного частотного ресурса смежными операторами. Актуальность рассматриваемых вопросов обусловлена стремлением к целенаправленному использованию спектра в широко распространенных сетях абонентского доступа, эксплуатирующих общие частотные каналы. Авторами предлагается модель совместного использования канального ресурса двумя операторами в целях эффективного снижения вероятности блокировки, что в конечном счете, позволяет повысить качество обслуживания. Разработанная в рамках предложенной модели система метрик использована для моделирования в Matlab 2012 соответствующего алгоритма реализации разделения частотного ресурса между двумя операторами сетей WiMAX. Полученные теоретические результаты позволяют прогнозировать улучшение пропускной способности сети и снижение вероятности блокировки. Результаты исследования на модели показали приемлемый результат в 0.0501 для вероятности блокировки и 21.4 Мбит/с пропускной способности при перераспределении 20%трафика, таким образом продемонстрировав преимущества разделения спектра в интересах повышения качества обслуживания абонентов сетями WiMAX.

Ключевые слова: WiMAX; спектр; блокирующая вероятность; пропускная способность; потери затенения; мощность и пропускная способность.

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