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Coverage Area Estimation for Mobile WiMAX Considering Cell Sectorization

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Abstract

In this work, coverage area has been estimated for mobile WiMAX considering cell sectoring. Erceg-Greenstein model and Cost-231 model have been used for path loss calculation for urban, suburban and rural areas. Frequency planning is also carried out to reduce the co-channel and adjacent channel interference. Analysis reveals that SNR is inversely proportional to the coverage are for different modulation schemes. Cell range also increases as the transmitted power increases.

Keywords: WiMAX, Cell Sectoring, CIR, SNR.

1. Introduction

WiMAX (Worldwide Interoperability for Microwave Access) is based on the IEEE 802.16 standard for Metropolitan Area Networks (MAN). Originally, the standard considered only fixed and nomadic links (802.16-2004) that could be used for “last mile” connectivity providing an alternate to T1 and DSL wired lines or as a back-haul for cellular or Wi-Fi networks [1]. However, Cell Sectorization and Frequency Planning are one of the core factors in mobile WiMAX. Each cell size varies depending on landscape, subscriber density and demand within particular region. Cells can be added to accommodate growth, e.g. creating new cells by overlaying, splitting, or sectoring existing cells. This technique increases the capacity of the system. Sectoring existing cells and then using directional antenna can also increase capacity [2]. The purpose of frequency planning is to ensure that an acceptable level of carrier-to-interference ratio (CIR) is supported by the wireless network to assure proper communication that meets operator requirements while making best use of the available spectrum [3]. Moreover, the main advantage of WiMAX is worldwide interoperability, the low cost for network implementation and no required separate voice and data network are the tremendous attractive features of WiMAX [4]. This paper states that, for sectorization, the coverage area increases and also signal to noise ration (SNR) improves with the decease of the distance, along with the effect of transmission power with coverage area.

2. Cell Sectoring Process

Cell sectoring is the process of dividing cells into sectors and replacing a single omni-directional antenna with a directional antenna. Common sector sizes are 120°, 90°, 60° and 30°. A typical structure is the tri-sector, known as clover, in which there are 3 sectors, each one served by separate antennas. Every sector is separated by 120° with respect to adjacent ones. If not then it is served by unidirectional antennas and 180° separation is done in bi-sectored cells [2]. However a cell is known as a simple geographical unit and a cluster contains the group of cells where no frequencies can be reused. It can be reused in another cluster and a large number of cells per cluster arrangement reduce interference to the system. Frequency reuse is a process of allocating channels in cellular system. Because of the unavailability of the spectrum at the cellular band, channel frequencies must be reused. If the number of available frequency is 7, the frequency reuse factor is 1/7, which implies that each cell is uses 1/7 of available frequencies. Frequency reuse introduces interference into the system [2]. Suppose for applying a cluster order k, the distance to co-channel cells D is only a function of the cell radius R:

$D = R + \sqrt{3+K}$ ....(1)

With increasing cluster order, the carrier-to-interference ratio C/I at a central base station (BS) receiving a signal from a subscriber station (SS) at the cell border is increasing. With γ as the path loss component, the C/I can be calculated to:

$$\frac{C}{I} = \frac{1}{6}\left(\frac{D}{R}\right)^{\gamma} \quad \text{(2)}$$

Dividing cells into sectors is an established technique for reducing the interference level in conventional cellular wireless networks. The cell is subdivided into several sectors. Each sector is covered by a sector antenna. As the power that is emitted backwards from the sector antenna is minimized, the number of interfering co-channel cells can be reduced. Analog to the previous equation, the expected C/I in a sectorized and clustered cell is given by the following equation in which M is the number of co-channel cells depending on the sector size [4]:

$$\frac{C}{I} = \frac{1}{M}\left(\frac{D}{R}\right)^{\gamma} \quad \text{(3)}$$

3. CIR Requirements

The impact of CIR can be proved by a general theory, known as Shannon's Theory –

$C = B\log 2(1 + CIR)$ ....(4)

where, C is the capacity of the channel and B is the channel bandwidth. As it is seen that the channel capacity is directly proportional to the channel bandwidth and also with CIR so definitely there is an impact for the CIR. Carrier-to-interference ratio impacts coverage since in areas where CIR falls below the required minimum level to demodulate a signal, an 'outage' area exists where a subscriber is denied service. So the operators must be careful for this [5].

4. Cell Design Procedure

Step 1:

At first, the frequency format has been assumed whether it is EVEN or ODD.

Step 2:

For the 6-sector cell, we have chosen EVEN form of frequencies in our diagram (which are B, D and F) for the first cell. These frequencies were used in 180° difference.

Step 3:

At first one centre cell is created and then from the edges of that particular cell other cells were created. (as shown in figure 1). Now, ODD frequency format (which is A, C and E) was set to those cells.

Step 4:

For the 3-sector cell, we have chosen EVEN form of frequencies in our diagram (which are B, D and F) for the first cell which was used in 120° difference. After that, EVEN forms of frequencies were inserted.

Step 5:

These procedures were repeated to cover more cells for both the 3-sector and 6-sector cells and there are no mandatory rules of inserting the forms of frequencies for any cell and it could be EVEN or ODD. 6-sector and 3-sector cell have been shown respectively.

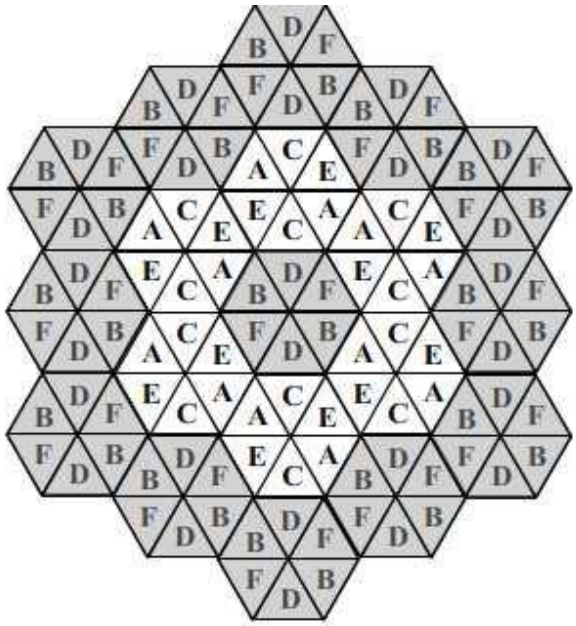

Fig. 1: 6-Sector cell

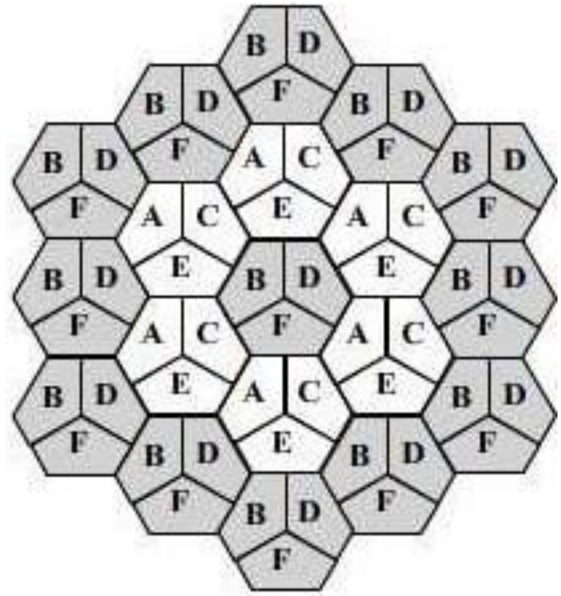

Fig. 2: 3-Sector cell

The adjacent and co-channel interference can occur for both the 3-sector and 6-sector cells, like the figure depicts for 6-sector cell, in the centered cell which is highlighted in grey, named as channel D has an adjacent channel interference with channel C highlighted in white. To minimize this interference, transmitting antenna power and gain from base station need to be controlled.

In the case of co-channel interference for 6-sector cell, in the white area, cells having same frequencies side by side say A to A, C to C and E to E. However the back lobe of this two antennas (say A to A) placed 180° apart from each other work as a Gain if they are aligned in-phase and have same polarization. But the side-lobes cause the interference mainly. In order to minimize this interference it also requires controlling the base station transmitting antenna power.

5. Frequency Planning Procedure

The post transition of 2495-2690 MHz for the BRS-EBS band plans are given below.

Step 1:

To do so, we have designed the 8-channel format and out of it 6 channels have been used, each contains 16.5 MHz band individually.

Step 2:

We first defined a guard band of 1 MHz before the BRS (Broadband Radio Service) and then the BRS which is known as the Multipoint Distribution Service, located in the 2.5 GHz band. These services were originally licensed as interleaved, 6 MHz channels.

Step 3:

After that we allocated the frequency bands for the channels.

Step 4:

Each channel was given 16.5 MHz each which has 3 parts named LBS (Lower Band Side), MBS (Middle Band Side) and UBS (Upper Band Side).

Step 5:

We have allocated 16.5 MHz from channel 1 to channel 4 which is LBS (Lower Band Side), then from J to K contains 6 MHz each which is MBS (Middle band Side) and at last, from channel 5 to channel 8 each channel contains 16.5 MHz, which is known as UBS (Upper Band side). Here LBS (Lower Band Side) and UBS (Upper Band side) are used for low power cellular and MBS (Middle band Side) for single power cellular.

Channel	GB	BRS 1	Channel 1			Channel 2			Channel 3			Channel 4		
Frequency	2496	2502	2507.5	2513	2518.5	2524	2529.5	2535	2540.5	2546	2551.5	2557	2562.5	2568

Lower Band Side (LBS)

J								K	BRS 2
2572	2578	2584	2590	2596	2602	2608	2614	2620	2624

Middle Band Side (MBS)

Channel 5			Channel 6			Channel 7			Channel 8		
2629.5	2635	2640.5	2646	2651.5	2657	2662.5	2668	2673.5	2679	2684.5	2690

Upper Band Side (UBS)

6. Coverage area Estimation

The main factors for calculating the coverage area are the path loss equation and the EIRP (Effective Isotropic Radiated Power). Regarding this different modulation schemes have been used both for uplink and downlink as QPSK, 16QAM, 64QAM. These different modulation techniques incorporate different data rates. In Mobile WiMAX QPSK, 16QAM, and 64QAM are mandatory in Down Link (DL) and in Up Link (UL) 64QAM is optional. Moreover in uplink QPSK 1/8 has been used for 70, 72 and 216 sub-carriers (pilot + data) respectively and 840 sub-carriers for 16QAM 1/2 [6]. The carrier frequency band of 2.5GHz with 10MHz channel bandwidth has been considered [7].

Erceg-Greenstein:

This model is used for Sub-Urban areas which are comprised by A-Terrain, B-Terrain and C-Terrain.

COST 231:

Used for Urban or Metropolitan areas and rural areas. For Urban areas the most popularly used model is ECC-33 Model for both large and small cities. For the *Erceg-Greenstein Model (Used for Sub-Urban Areas*) path loss equation is:

$$PL\ (NLOS) = A + 10\gamma \operatorname{Log}(d/d_o) + FD + (\Delta PL_f + \Delta PL_h) \quad (dB) \qquad (5)$$

Where, A represents Free Space Path Loss (dB), γ is the Path Loss Exponent, ΔPL_f represents Frequency Correction Term, ΔPL_h is the Receiver Antenna Height Correction term and FD is the Log Normal Fading. For the *Cost-231 Model (Used for Urban, Rural and Open Place)* path loss equations are:

$$PL\ (Urban) = 46.3+33.9\operatorname{Log}(f_c)-13.82\operatorname{Log}(h_b)-a(h_m)+[44.9-6.55\operatorname{Log}(h_b)]*\operatorname{Log}(d)+C_M \quad (dB) \qquad (6)$$

$$PL\ (Sub\text{-}Urban) = PL\ (Urban) - 2\,[\operatorname{Log}(f_c/28)]^2 - 5.4 \quad (dB) \qquad (7)$$

$$PL\ (Rural) = PL\ (Urban) - 4.78\,[\operatorname{Log}(f_c)]^2 + 18.33\operatorname{Log}(f_c) - 35.94 \quad (dB) \qquad (8)$$

$$PL\ (Open) = PL\ (Urban) - 4.78\,[\operatorname{Log}(f_c)]^2 + 18.33\operatorname{Log}(f_c) - 40.94 \quad (dB) \qquad (9)$$

In the case of *Effective Isotropic Radiate Power (EIRP)* the equations for both downlink and uplink:

EIRP (Downlink) (dBm) = BS Power (dB) + BS Antenna Gain (dBi) + Cyclic Combining Gain (dB) + Pilot Power Boosting Gain (dB) (10)

EIRP (Uplink) (dBm) = MS Power (dB) + MS Antenna Gain (dBi) (11)

[BS=Base Station, MS=Mobile Station]

So the coverage area s for both downlink and uplink respectively, can be obtained as:

Table 1: Coverage area estimation for different modulation schemes (downlink)

Modulation Schemes	Coverage Areas in km						
	Open	Rural	Suburban Flat	Suburban Moderate	Suburban Hilly	Urban Small City	Urban-Large City
QPSK 1/8	5.13	3.69	1.05	0.97	0.79	0.55	0.45
QPSK 1/2	3.69	2.66	0.79	0.74	0.62	0.40	0.33
16 QAM 1/2	2.33	1.68	0.53	0.51	0.44	0.25	0.21
64 QAM 1/2	1.68	1.21	0.40	0.39	0.35	0.18	0.15

Table 2: Coverage area estimation for different modulation schemes (uplink)

Modulation Schemes	Coverage Areas in km						
	Open	Rural	Suburban Flat	Suburban Moderate	Suburban Hilly	Urban Small City	Urban-Large City
QPSK 1/8 (70 SC)	4.96	3.57	1.02	0.94	0.77	0.54	0.44
QPSK 1/8 (72 SC)	3.54	2.55	0.76	0.72	0.60	0.38	0.31
QPSK 1/8 (216 SC)	2.20	1.58	0.50	0.49	0.42	0.24	0.19
16 QAM 1/2 (840 SC)	1.04	0.75	0.26	0.26	0.24	0.11	0.09

To estimate the coverage areas, penetration loss and log normal fade margin are neglected when the path loss is calculated because, Erceg-Greenstein model and Cost-231 model are developed considering penetration loss and log normal fade margin in case of both Downlink and Uplink [6].

7. SIMULATIONS

7.1 Effects of SNR

In mobile WiMAX, SNR varies over the distance, frequency reuse factor and allocated sub-carriers (Data + Pilot) and antenna power. SNR improves with the decrease of distance and increase of frequency reuse factor, allocated sub-carriers and antenna power. In case of downlink and uplink, it is shown in Fig-3 and Fig-4 accordingly. Based on SNR values, BS makes decision to use the appropriate modulation technique.

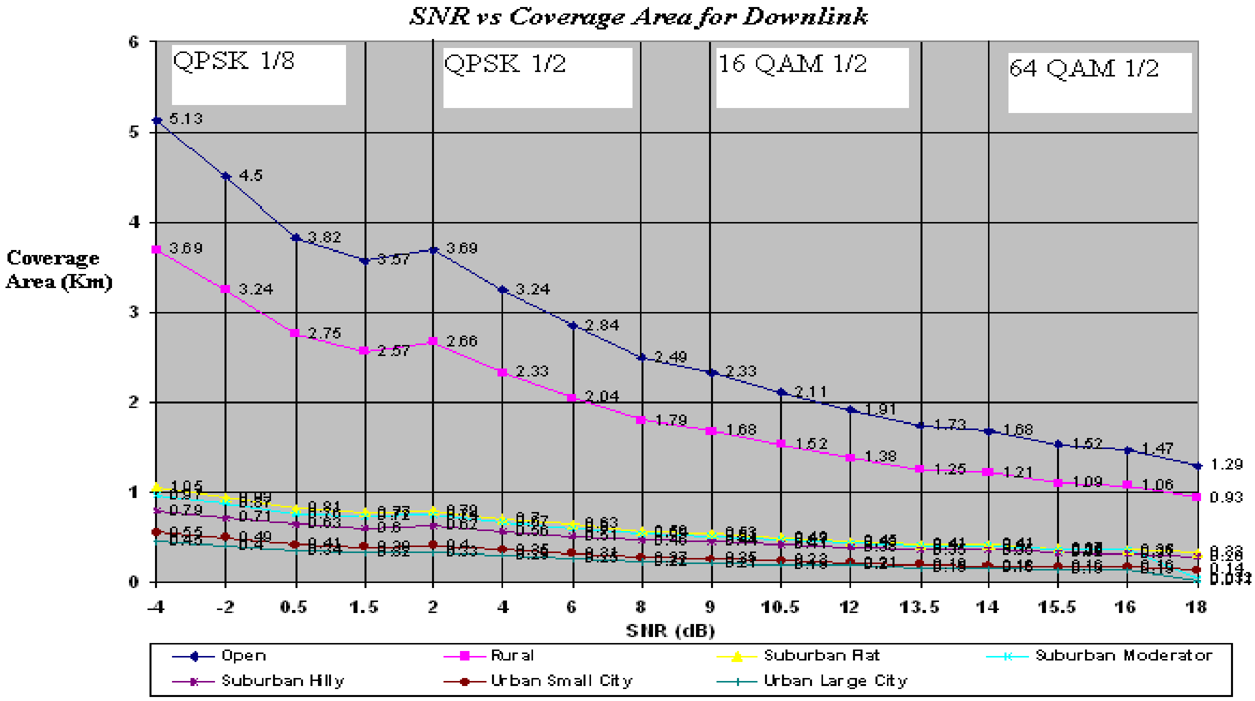

Fig. 3: Changes in coverage area for different SNR for different modulation schemes (Downlink)

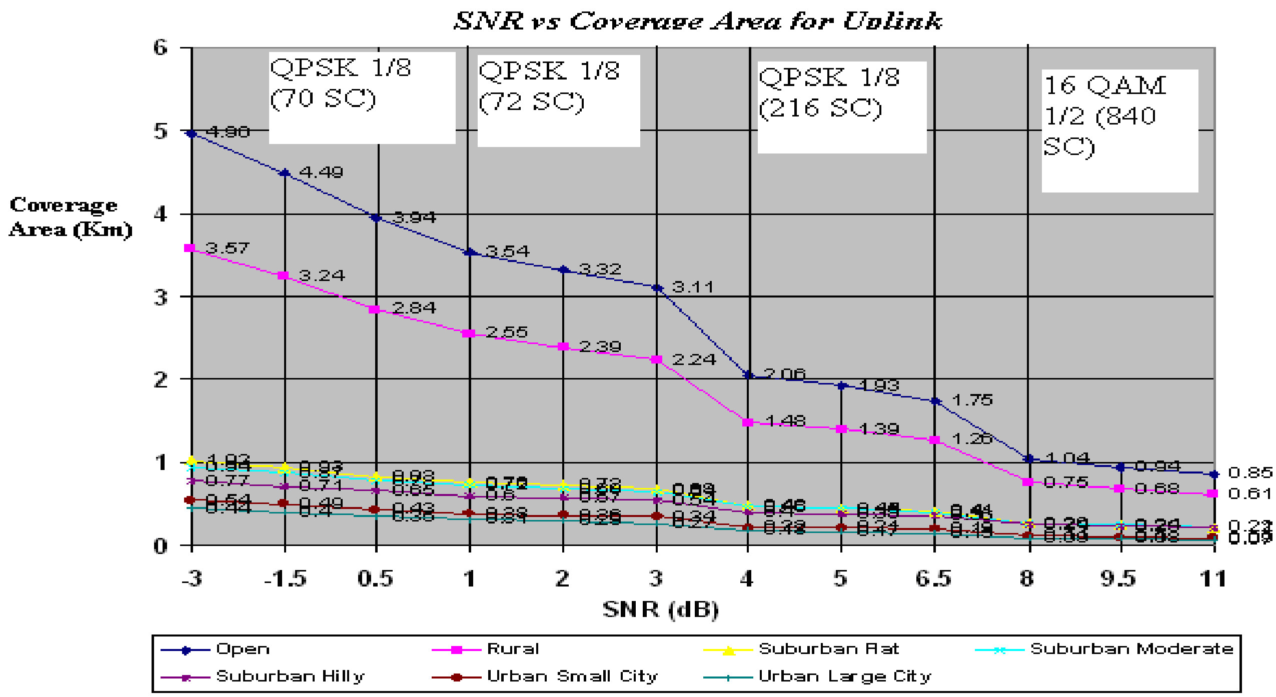

Fig. 4: Changes in coverage area for different SNR for different modulation schemes (Uplink)

7.2 Effects of BS Transmitted Power

From Fig-5 and Fig-6, it can be seen that the coverage area increases with the increase of base station transmit power, both for the downlink and uplink respectively. Here the MIMO (Multiple Input Multiple Output) antenna technology at BS (Base Station) and MISO (Multiple Input Single Output) antenna technology at MS (Mobile Station) end have been considered. As the BS transmitted power decreases, coverage area increases.

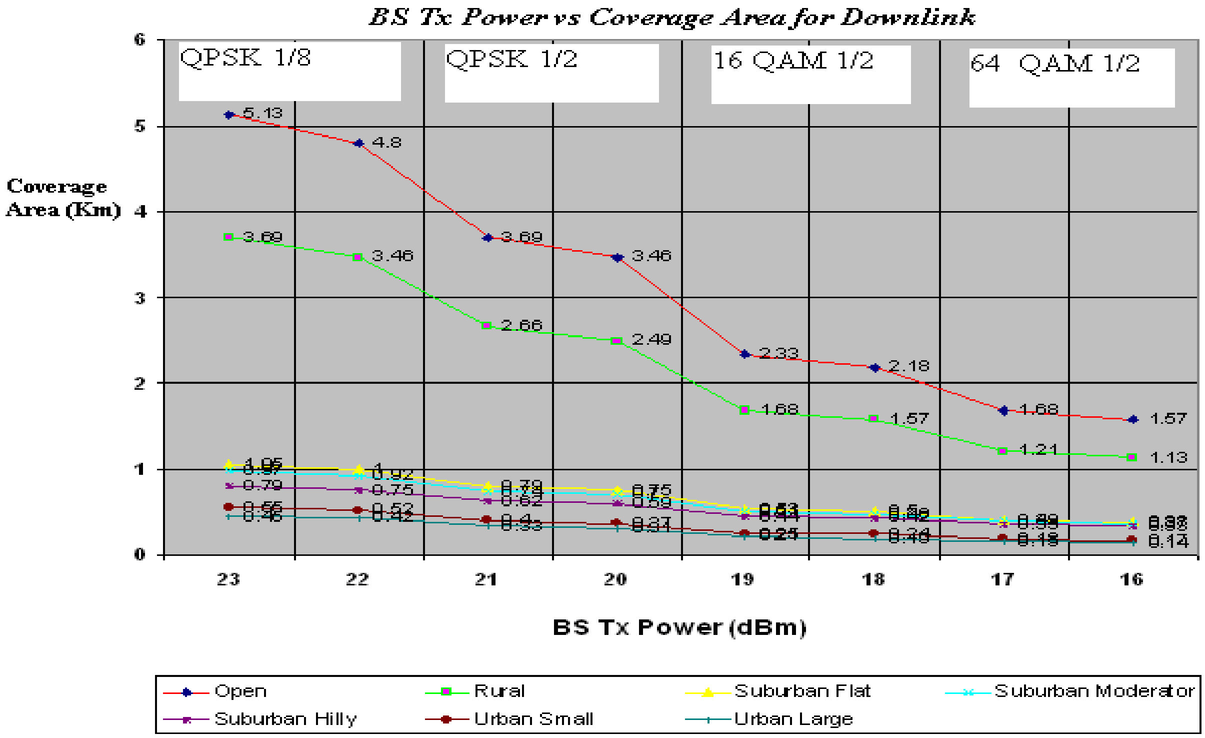

Fig. 5: Changes in coverage area for different BS Tx power for different modulation schemes (Downlink)

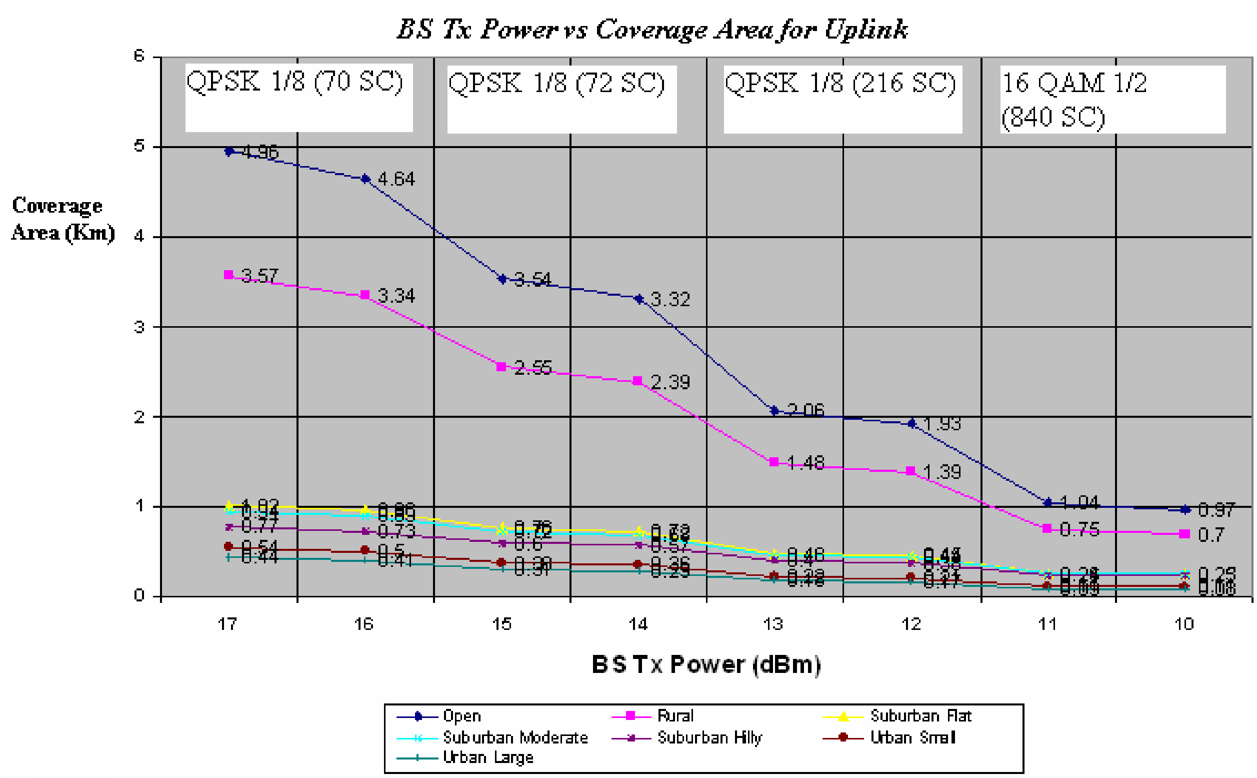

Fig. 6: Changes in Coverage Area for different BS Tx power for different modulation schemes (Uplink)

Conclusion

In this work, the effects of SNR and transmit power on coverage area have been carried out. Observation shows that when the coverage area is high, SNR is low. The analysis reveals that

SNR and effect of transmission power are directly dependent on coverage area. With a lower transmitted power the BS can cover smaller areas, i.e. smaller coverage area. With a minimum transmitted power, the coverage area can be increased by degrading the number of allocated sub carriers. Finally analysis reveals that in all of the above circumstances, coverage area for uplink is lower than that of downlink and in addition, a frequency plan for 16.5 MHz channel bandwidth has been done for both 3-sector cell and 6-sector cell.

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