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Effect of Operating Frequency on Performance of LTE and LTE-Advanced Systems

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ABSTRACT: A vast pool of frequency bands from 450 MHz to 3.6 GHz is available for deployment of LTE and LTE-Advanced networks. But with increase in the operating frequency path loss increases which in turn impacts the coverage area of a base station. Accordingly the number of base stations increases which leads to increase in the cost of deployment. Availability of spectrum in high frequency range is not an issue but it has its own pros and cons. This paper discusses the effects of deploying networks at high frequency versus deployment at low frequencies. The LTE system level simulator by Vienna has been used to study the changes in path loss with changes in operating frequencies of 0.8 GHz to 2 GHz.

KEYWORDS: Long term evolution, operating frequency, path loss, rural and sub urban environment, Long term evolution - Advanced.

I.INTRODUCTION

Long Term Evolution (LTE) was a revolutionary step to achieve higher data rates than those offered by 3G cellular systems. Data rates of upto 500Mbps in uplink and 1 Gbps in downlink were targeted by 3GPP group. For supporting such speed, in late 2009, ITU received a proposal for considering LTE-Advanced as a candidate 4G system in the mobile communication world. In March 2011, 3GPP had standardized LTE-Advanced [1] as an advancement to the LTE technology. Various research proposals like relaying, CoMP, SU-MIMO and diversity MIMO, carrier aggregation, Hybrid OFDMA and SCFDMA in uplink, ICICI etc. have been worked upon during the research phase [2]. Amongst the requirements stated in the 3GPP technical report [3], main concentration was compatibility of the LTE Advanced systems with the existing LTE networks. The study carried out by 3GPP has been discussed in [4].

Network coverage is an important issue for the mobile cellular communication service providers. The deployment of cellular systems takes into account the various propagation characteristics of the communication channel. There is a vast diversity in the cellular environments. Those under study are the urban, rural and suburban, forest, sea etc. Suitable radio propagation models describing the behaviour of signal travelling from transmitter to receiver have been discussed over a long time in research papers [5-11]. Well known standard models are the COST 231-Hata, COST 231-Walfisch-Ikegami, Hata-Okumura , Lee model etc. Loss that occur due to the travelling of signals from transmitter to receiver is called the pathloss which is measured with the help of these propagation path loss models.

The document by 3GPP, a version of Release 10 [12], states the operating bands of E-UTRA systems. It states that the frequency of operation of EUTRA systems extends from 699 MHz to 3.8 GHz in UL and 729 MHz to 3.8 GHz in DL considering the FDD and TDD duplex modes.

II.RESEARH WORK

The feature of usage of LTE in multiple bands of spectrum has been explored over a period of time. Studies have been conducted for evaluating the performance of the system in various frequency bands. In [13] a thorough comparison of system performance in 800 MHz band has been made with 1800 MHz band and UMTS 900 MHz band, considering

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few of the primary measurement parameters such as Referenced signal received power (RSRP), Referenced signal received quality (RSRQ), Signal to Interference-noise ratio (SINR) and throughput. It emphasized the fact that 800MHz band provided twice the coverage than the 1800 MHz band with less number of base stations. The throughput for LTE 800 is more than UMTS900 but with degradation towards the cell edges. The article by ZTE [14] discusses the inherent features of the 700 MHz band for LTE technology. It reveals the fact that using a 700 MHz band (in various scenarios) the coverage provided by a single site is about 7-8 times that offered by the 2.6 GHz band, thereby requiring very few sites operating at 700 MHz frequency. But the cost of having more number of sites operating at higher frequencies is compensated by getting an increase in the capacity with such high frequency operation networks. Thus operators building their networks on higher frequency of 1.7 GHz, 1.9GHz and 2.5 GHz would have higher capacity as compared to those using the 700 MHz band.

III.PROPAGATION LOSS

Free space path loss equation for far field situations is given as,

$$FSPL= (4*\Pi*d / \lambda)^{2} \text{ or } (4*\Pi*d*f / c)^{2} \qquad \text{.......} (1)$$

Where, FSPL is the free space path loss, d is the distance of receiver from transmitter in metres, λ is the signal wavelength in meters, f is the signal frequency in hertz and c is the speed of light in vacuum in meters per second.
Above equation shows that propagation loss of radio waves is frequency dependent and increases with frequency. Higher frequency bands tend to have higher propagation losses. These losses are due to of many effects, such as free-space loss, refraction, diffraction, reflection, aperture-medium, coupling loss, and absorption. Path loss is also influenced by terrain contours, environment (urban or rural, vegetation and foliage), propagation medium (dry or moist air). Propagation loss is calculated using different path loss models which depict the dependency of propagation loss on both the distance 'd' between receiver and transmitter and the operating frequency. Discussion about the 3 kinds of models: Empirical models, semi-deterministic model and the deterministic models have been done in [15]. Low frequency signals tend to have less propagation losses as compared to high frequency signals. The section IV consists of a detailed analysis to support the same.

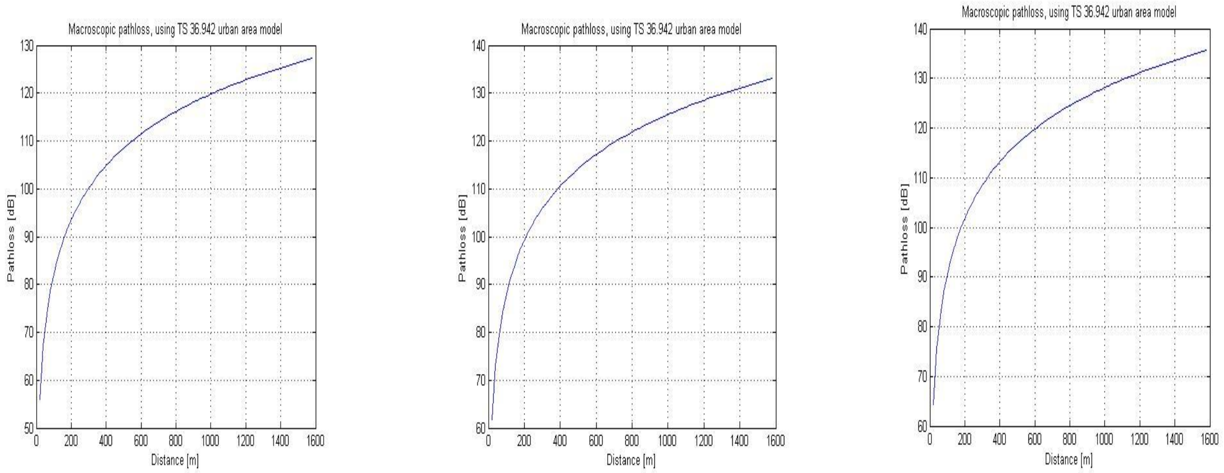
IV.SIMULATION AND RESULTS

LTE system level simulator [16] has been used for determining the effect of increasing configuration frequency on the overall performance of system both in rural and urban environment. The system parameters have been stated in the table 1. The system layout consists of hexagonal grid of eNodeBs with 3 sectors/ eNodeB and randomly placed user equipments (UE).

Table 1: SYSTEM PARAMETERS

Deployment Scenario	Urban macro-cell	Rural macro-cell
User mobility model	Fixed and identical speed of all UEs, randomly and uniformly distributed direction	Fixed and identical speed of all UEs, randomly and uniformly distributed direction
Base station (BS) antenna height	25 m, above rooftop	35 m, above rooftop
Total BS transmit power	46 dBm for 10 MHz, 49 dBm for 20 MHz	46 dBm for 10 MHz, 49 dBm for 20 MHz
UE antenna system	Up to 2 tx Up to 2 rx	Up to 2 tx Up to 2 rx
Minimum distance between UE and eNodeB	>= 25 m	>= 35 m
Inter-eNodeB distance	500m	1732m
Thermal noise level	–174 dBm/Hz	–174 dBm/Hz

The figure 1 shows the variations in path loss with distance for different configuration frequencies in urban environment. Here due to dense distribution of the user equipments the ideal inter eNodeB distances should be 500 meters. It is seen from the figure that at the same distance of 500 meters the macroscopic path loss increases with the increase in configuration frequency.



(a) (b) (c)

Fig. 1 Effect of increasing operating frequency (a) 0.8 GHz (b) 1.5 GHz (c) 2 GHz, Urban environment

The path loss occurring at different frequencies has been tabulated in the table 2. It shows that higher frequencies tend to experience more path loss as compared to lower frequencies. A network operating at 800 MHz will have less path loss as compared to the one using the 2 GHz band. A GSM system using 800 MHz band will tend to exhibit less pathloss than LTE systems using the 2 GHz and higher frequency bands. Hence, for networks deployed at higher frequencies the inter eNodeB distances in urban environment should be 500 meters to ensure that the channel quality is good and the users get their desired quality of service.

Table 2: Operating frequency and path loss in urban environment

Operating Frequency of cell sites	Path loss
0.8 GHz	108 dB
1.5 GHz	115 Db
2.0 GHz	118 dB

LTE-Advanced systems, an enhancement to the LTE systems, introduce the relaying technology to compensate these path losses and boost up the signal strength between the base station and the user equipments. Here many low power nodes are placed between the base station and UEs. These nodes process the signal to the desired strength and quality and forward it to the next relay node or the UE in the link. This technique provides a good solution to the increased cost involved in deploying high power eNodeBs for taking care of the path losses encountered in the communication link.

The figure 2 shows the effect of frequency on macroscopic path loss in rural environment. From the table it can be seen that at the distance of about 2000 meters the path loss increases with increase in frequency. Ideally, the inter eNodeB distance in rural environment should be 1732 meters.

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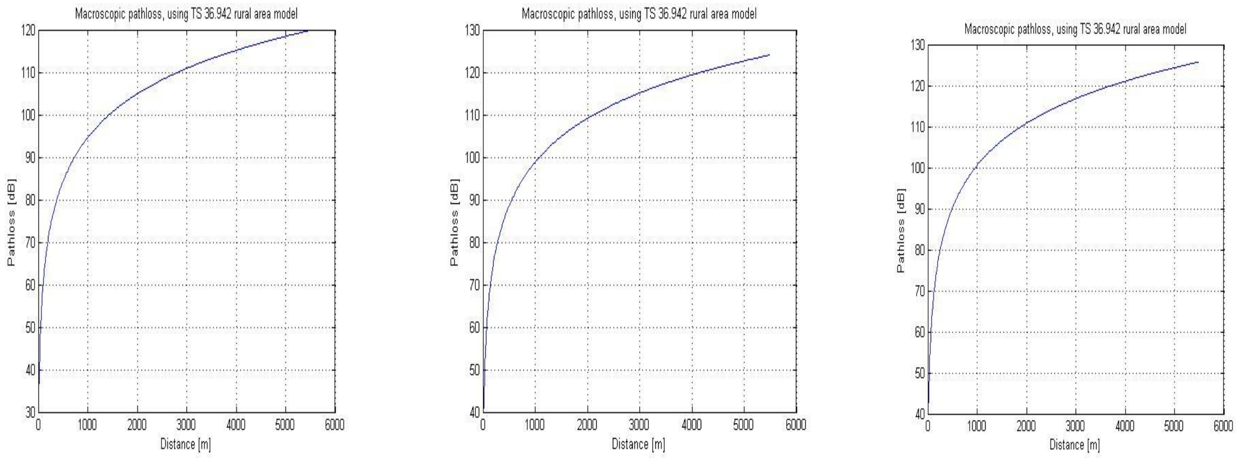


(a) (b) (c)

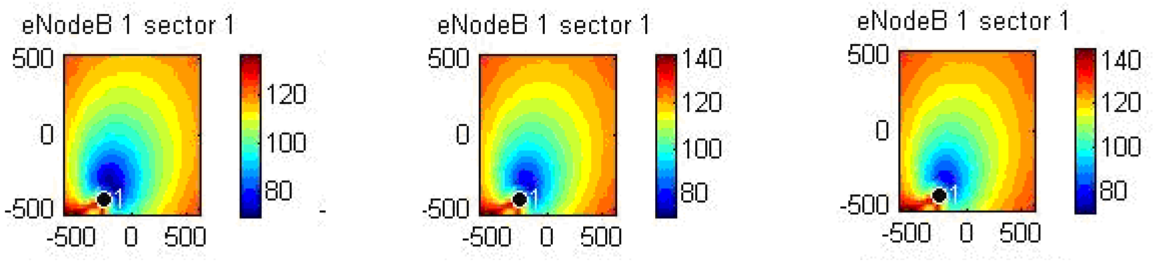
Fig. 2 Effect of increasing operating frequency (a) 0.8 GHz (b) 1.5 GHz (c) 2 GHz, Rural environment

Table 3 shows the variations in the path loss at different frequencies for the rural environment. Networks in rural environments tend to experience less path loss as compared to those in the urban environment as the signal experiences less amount of diffraction, reflection, scattering and other such phenomenon which tend to decrease the signal strength and hence increase the path loss.

Table 3: Operating frequency and path loss in rural environment

Operating Frequency of cell sites	Path loss
0.8 GHz	105 dB
1.5 GHz	109 dB
2.0 GHz	112 dB

The coverage at 0.8 GHz, 1.5GHz and at 2.0 GHz, for the urban environment, for sector 1 eNodeB1, is shown in figure 3. It can be deduced that wider coverage is obtained at 0.8MHz than at 2GHz. This is because of signals of high frequencies travel less distances as compared to lower frequency signals. Low frequency signals have deep penetration.



(a) (b) (c)

Figure 3: Coverage at (a) 0.8 GHz, (b) 1.5 GHz, (c) 2 GHz, Urban environment

Networks deployed in urban areas, where there are more obstacles, tend to exhibit more path losses at higher frequencies than those deployed at rural areas. The figure 4 shows the coverage obtained in rural area at different operating frequencies. Rural areas have less density of buildings so the signals do not undergo much penetration losses. For a system operating at same frequency the signal strength is better in rural areas as compared to urban areas. Thus selection of operating band has a significant effect on the coverage distance and the quality of service offered to the

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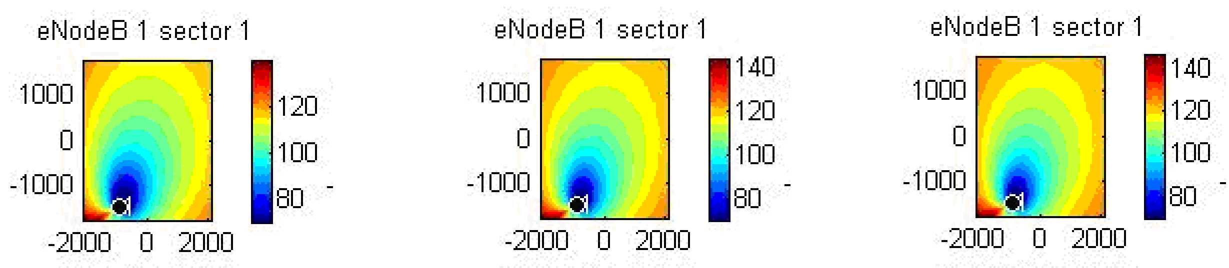
users. Operators would prefer to select an operating band which will provide them a large coverage as well as high penetration capability and at the same time reducing their expenses with the use of fewer cell sites operating at low frequency



(a) (b) (c)

Figure 4: Coverage at (a) 0.8 GHz, (b) 1.5 GHz, (c) 2 GHz, Rural environment

LTE – Advanced system, considers using frequency bands [17] as shown in table 4. The feature of flexibility of combining multiple frequency bands (low as well as high frequency bands) to enhance the performance of the system has become possible due to the technological component of carrier aggregation, a key component of LTE-Advanced systems. Here with the use of contiguous and non-contiguous carrier aggregation techniques, over the entire spectrum, a large bandwidth of 100 MHz is achieved which supports higher data rates (the key requirement of 4G systems), as well as provide wider coverage using underlay and overlay schemes of deployment.

Table 4: IMT frequency bands

Frequency band	Usage
450-470 MHz	To be used globally for IMT systems
1710-2025 MHz	
2110-2200 MHz	
2300-2400 MHz	
2500-2690 MHz	
698-960 MHz	To be used in specific countries
3400-3600 MHz	

V. CONCLUSION

Mobile communication systems operate at frequencies ranging from 450 MHz to 3600 MHz. Different frequency bands experience different propagation losses as per the mobile cellular environment. There is about 10 db of propagation loss in urban environment and 8dB in rural environment as the operating frequency is increased from 800 MHz to 2 GHz. As propagation losses increase due to various reasons mentioned before, the coverage of the network reduces. Hence using lower operating frequency ensures wider coverage. This reduction in coverage area of a base station eventually results in deployment of more base stations to cover a given area. A network deployed at 1900 MHz takes about 2-4 times as many sites as that deployed at 850 MHz. Thus deployment of LTE network at high frequency is costly but the there is an improvement in the capacity of the system. The ratio depends upon various factors such as path loss, the link budget, cell tower height, the terrain of the area being covered. In densely populated areas, low frequency sites can cause inter cell interferences but down tilting the base station antenna can reduce the coverage and thereby the interference. Thus, depending upon the requirement of the operator and the availability of the spectrum the providers may deploy systems operating at higher or lower frequency bands.

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VI. FUTURE WORK

In future, bands between 3-5 GHz and even 60 GHz will be utilized for mobile wireless communication [18]. In those deployments, the higher propagation path losses encountered would be compensated by having an increased no. of cell sites under the macro cell. Improved coordination mechanisms will have to be worked upon. Further research would be carried out for exploring the features of higher frequency bands as well as lower [<700 MHz] bands and studying the various parameters affecting propagation characteristics of these bands. LTE-advanced system environment will be considered for research work.

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