Data Communication Quality in Mobile Broadband Access Networks: Radio Propagation Environment Impact and End-User Achievements

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***Abstract*—The need for efficient radio channel quality measurement to support planning, operations and management of data communication networks has increased nowadays. An important parameter for measuring data communication quality of a radio network is channel throughput. In this research work, the impact of end-user location and radio propagation channel environmental parameters on channel throughput performance has been experimentally investigated in an operational 3G networks, with upgraded HSDPA technology. Firstly, results show that near-far effect have enormous impact on channel throughputs especially as the end-user move towards the cell edges. This implies that the packet drop rate on the packet data communication links increases as the user move towards the cell edges. Secondly, it has been shown how the end-user data throughput performance drops as propagation loss exponent increases. This implies that data communication quality in HSDPA mobile broadband is environment dependent. Hence, to provide a good end-user experience, the influence of different radio propagation environment on mobile data communication quality must be considered in the design and deployment of cellular networks.**

Keywords—Mobile broadband; radio propagation channel; radio propagation environment; end-user location; channel throughput

I. Introduction

The demand for high data rate application on mobile terminal devices have increased remarkably, thus making mobile broadband a reality worldwide. This can be seen in the market invasion of diverse smartphones, tablets, and palmtops, USB modems and other media-hungry mobile devices with fresh innovative services. This in turn has led to the rapid deployment of broadband access communication systems such as Universal Mobile Telecommunication System (UMTS), High Speed Downlink Packet Access (HSDPA), and High Speed Uplink Packet Access (HSUPA), etc. Presently, the deployment of higher wireless communication standards such as WIMAX and LTE on existing ones has been adopted worldwide. This is to meet customer's mobile data communication demand and cater for spectrum shortages. According to Cisco Visual Networking Index [1], the overall mobile data traffic is expected to grow to 30.6 exabytes per month by 2020, which is an eightfold increase over 2015. Also, it has been reported in [2], that the GSM/EDGE and WCDMA/SSPA will continuous to be the worldwide technology even after 2020, in terms of mobile data subscription and consumption.

As the demand for various multimedia services increases on daily basis, network operators are also struggling to keep up with the demand, especially in the capacity of providing good internet services with high data throughput rates on deployed mobile networks. One of the factors that place fundamental limitation on the performance of wireless mobile data communication networks is the radio propagation channel. This is because of most radio networks that are deployed in complex environment with various blockades in between the transmitter and the end user receiver. This in turn leads to reflection, diffraction and scattering of transmitted radio signals and the resultant effect is signal propagation path loss and poor service quality at the end user terminal. The signal propagation loss varies greatly depending on the incidence of buildings and the population density in the terrain i.e. urban, suburban and rural.

Therefore, it is important to reliably and quantitatively estimate in realistic settings, of how radio propagation channel and environment impact on data communication quality in mobile broadband access networks. This is to assist radio network engineers plan future data communication networks as well as optimize existing one. In this research work, an attempt have been made to quantify and provide a clear image on how the radio channel propagation environmental parameters impact end-user data communication throughput quality in an operational 3G networks, with upgraded HSDPA technology.

II. Radio Propagation Channel

The deterioration of radio signal quality due to radio propagation channel is linked to three different causes which are pathloss, shadowing and multipath. A basic signal propagation model that captures both pathloss and shadowing is formulated as [3]:

$$\mathrm{P}_r = K.\left(\frac{d}{d_0}\right)^{\alpha}\psi.P_t \tag{1}$$

The propagation pathloss, PL is derived from (1) by:

$$PL = \frac{\mathrm{P}_r}{P_t} = K.\left(\frac{d}{d_0}\right)^{\alpha}\psi. \tag{2}$$

In dB, (2) becomes

$$PL(dB) = K + 10.\alpha\log_{10}.\left(\frac{d}{d_0}\right) + \psi_\sigma \tag{3}$$

where P_r and P_t are the received signal code power at the mobile terminal and transmit power respectively. The d is the arbitrary transmitter-receiver separation distance, K is the free space loss component at distance at reference d_o. ψ is the log-normal component with random zero mean Gaussian distributed variable and standard deviation σ. The propagation loss exponent, α is the environment dependent parameter as shown in Table 1.

TABLE I. PROPAGATION LOSS EXPONENT FOR DIFFERENT PROPAGATION ENVIRONMENT [3]

Environment	Propagation loss exponent, α
Free space	2
Urban cellular area	2.7 to 4.0
Shadowed urban cellular area	3 to 5
In-building LOS	1.6 to 1.8
Obstructed Indoor	4 to 6
Obstructed in factory	2 to 3

The first point of focus in this work is on the parameter α. It is an important environmental based modelling parameter in radio signal propagation. It can be determined from measured propagation loss data using regression analysis as follows:

$$E(\alpha) = \sum_{i=1}^{k}\{PL_m - PL_p\}^2 \tag{4}$$

where PL_m is the measured propagation loss as expressed in (9) and PL_p is the predicted propagation, which is represented by the log-distance component of (3), and after substitution, we have,

$$E(\alpha) = \sum_{i=1}^{k}\left\{PL_m - K - 10.\alpha\log_{10}.\left(\frac{d}{d_0}\right)\right\}^2 \tag{5}$$

Differentiating (5) with respect to α gives

$$\frac{\delta E(\alpha)}{\delta\alpha} = -20.\alpha.\log_{10}\left(\frac{d}{d_0}\right)\sum_{i=1}^{k}\left\{PL_m - K - 10.\alpha\log_{10}.\left(\frac{d}{d_0}\right)\right\} \tag{6}$$

Equating $\frac{\delta E(\alpha)}{\delta\alpha}$ to zero and after dividing by

$-20.\alpha.\log_{10}\left(\frac{d}{d_0}\right)$, we have,

$$\sum_{i=1}^{k}\left[PL_m - PL(d_o)\right] - \sum_{i=1}^{k}\left[10.\alpha\log_{10}.\left(\frac{d}{d_0}\right)\right] = 0 \tag{7}$$

The propagation exponent α is determined from (7) by

$$\alpha = \frac{\sum_{i=1}^{k}\left[PL_m - PL(d_o)\right]}{\sum_{i=1}^{k}\left[10.\log_{10}.\left(\frac{d}{d_0}\right)\right]} \tag{8}$$

Another radio network parameter often used for accessing the optimal performance of data communication in mobile radio propagation channels is Signal to Noise Ratio (SNR). It is defined as the power ratio between the received signal strength and the background noise also explained as the SNR describes how strong an intended signal is in comparison to the background noise. Where P_r measures the amount of signal energy received at the antenna, SNR measures operational conditions of the propagation channel where interference and noise is taken in consideration [5]. The *SNR* is related to P_r by [4]-[6]:

$$SNR = \frac{34}{\left(1 + \frac{5.2\times10^{13}}{(102 + RSSI)^4}\right)^{\frac{1}{9}}} \tag{9}$$

where *RSSI* Received Signal Strength Indicator. *RSSI* takes into account both received signal power, P_r of the pilot channel (CPICH) and the energy per chip to noise ratio, Ec/N_0. Mathematically, it is calculated in dBm by:

$$RSSI\ (dBm) = P_r\ (dBm) - Ec/N_0\ (dB) \tag{10}$$

III. CHANNEL THROUGHPUT

In literature [7]-[11], different terminology have been used to express the concept of throughput, among which are average user data throughput, perceived user data throughput, forward link average aggregate throughput, maximum theoretical throughput, maximum sustained throughput, network throughput, minimum user throughput and channel throughput or channel capacity. In this work, the focus is channel throughput concept. It is defined as the maximum rate at which reliable communication is possible over a channel or system. Mathematically the channel throughput performance evaluation is often based on Shannon's formula:

$$C = \mathrm{W}\times log_2\,(1+SNR)\ in\ bps \tag{11}$$

where W is bandwidth of the channel (Hz) and SNR is signal to noise ratio (in linear scale).

In [12], (11) has been modified to yield,

$$C = N.W.log2\,(1+\beta.SNR)\;in\;bps \tag{12}$$

where N is the number of antennas and α is the correction factor, with typical values in-between 0.1 to 1.

IV. Method of Data Collection

The propagation measurements were conducted in *Lagos* a western part of Nigeria. *Lagos* is typical urban environment with a mix of residential (mostly of two to four stories), commercial, industrial and open area, among others. The data was collected with field test tools consisted of Sony Ericson Mobile handset, Test cable, Laptop, Socket, Compass, Power inverter, Global Positioning System GPS, MapInfo digital maps and a Vehicle. For the measurement procedure, a Sony Ericson Mobile phone was connected to a laptop running the *TEMS* software. Using the tools, signal strength and quality log data files were acquired around the possible routes around base station *(BS)* transmitters and stored in the computer for further analysis. Average height of the investigated *BS* antenna ranges between *32 to 45 meters* above ground level, with comparatively same transmit power. In all the study locations, BS was equipped three sectored antennas with inbuilt features, which enables them to radiate in three directions at *2100 MHz*. The location of the *BS* antenna was a determining factor for site selection. Four *BS* locations, comprising of one LOS environment (i.e. location 1) and three *NLOS* environment were considered for investigation.

The measured propagation loss has been computed from measured signal power as follows:

$$Pl_m\,(dB) = P_r(dBm) - (EIRP)dB + G(\theta,\Phi)\,dB + Gr(dB) - Lr(dB) - Lt(dB) \tag{9}$$

where PL_m is measured propagation loss, Pr is the measured signal power, *EIRP* is the effective isotropic radiated power, $G\ (\theta,\Phi)$ represents the antennas gains along the line defined by the transmit and receive antennas, Gr is the gain of the receiving antenna, Lr is the feeder losses of the receiver and Lt is the feeder losses of the transmitter.

V. Results and Analysis

The results presented graphically in Fig. 1 to 4 show the channel throughput performance at end-user terminal, taken at different measurement point from the *BS* transmitter. It is clearly seen here that the channel throughputs are higher in areas closer to the *BS* and reduces gradually as the user move towards the cell edges. This also shows that the packet drop rate on the packet data communication links increases as the user move towards the cell edges. Widespread fluctuations in channel throughput may be due to variations in the radio channel conditions like signal quality, path losses, etc. at different measurement location.

Fig. 5 to 8 shows the channel throughput as a function of measured P_r data points at the different locations using (12). The fitted polynomial trend lines is done on the graphs to further predict the correlation between the throughput and P_r. From the trend lines, there seems to be a linear relationship between the throughput and P_r values as expected, where a *1 dB* increase in P_r gives a *1 Mbps* increase in the *throughput* values. But, for higher P_r values, the throughput approaches to a limit, especially in Fig. 6 and 8 which may be caused by saturation effects at the end-user mobile terminal. The graphs almost flatten off between *2.45 Mbps* and *5.56 Mbps* with respect to different P_r values, which indicates that interference may be present in the studied HSDPA network. This presents that the optimal performance can be achieved if P_r is above a threshold value when no interference or background noise is available.

Specifically, the chart in Fig. 9 is plotted to present the impact propagation environment on mean channel throughput performance. Here, the environment based evaluation parameter is the propagation exponent, α and its value has been calculated for each study locations following the regression analysis procedure of (4) to (8). It can be observed in Fig. 9 that the data throughput performance decreases as propagation loss exponent increases, from *LOS* to *NLOS* conditions. It means the end-user channel throughput communication rates in *HSDPA* mobile broadband network is highly susceptible to different propagation environmental conditions, especially under *NLOS* cases where transmitted signal energy is affected by a variety of propagation mechanisms such as reflection, diffraction, absorption and scattering.

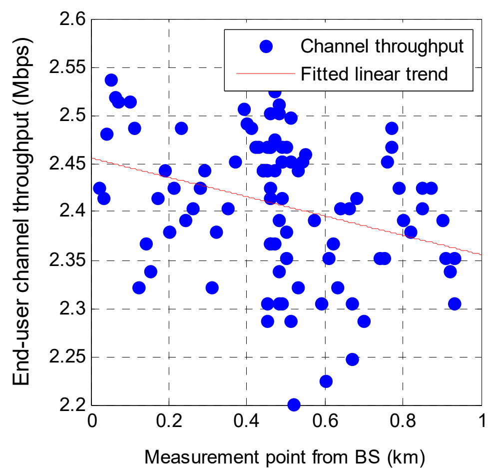


Fig. 1. Dependency of channel throughput on measurement slots away from the BS in location 1 (LOS case).

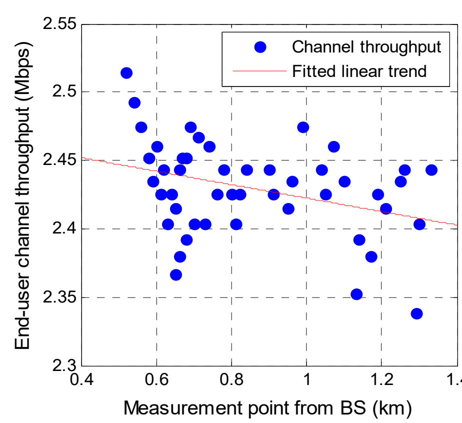


Fig. 2. Dependency of channel throughput on measurement slots away from the BS in location 2 (NLOS case).

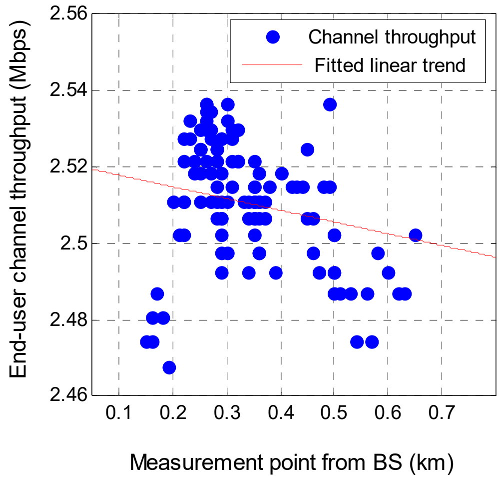


Fig. 3. Dependency of channel throughput on measurement slots away from the BS in location 3 (NLOS case).

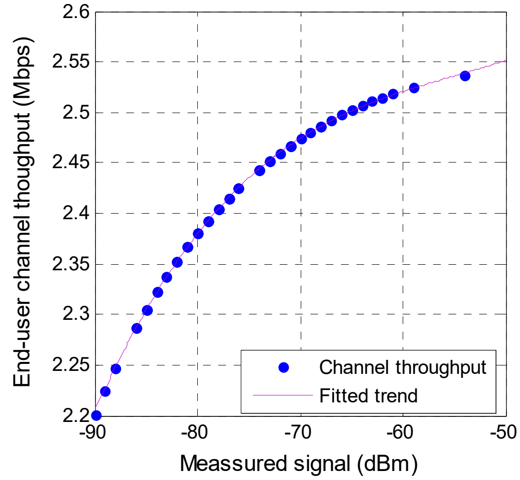


Fig. 6. Dependency of channel throughput on measured signal slots away from the BS in location2 (NLOS case).

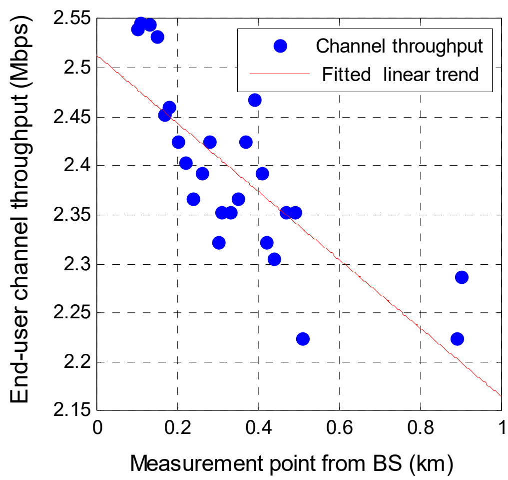


Fig. 4. Dependency of channel throughput on measurement slots away from the BS in location 4 (NLOS case).

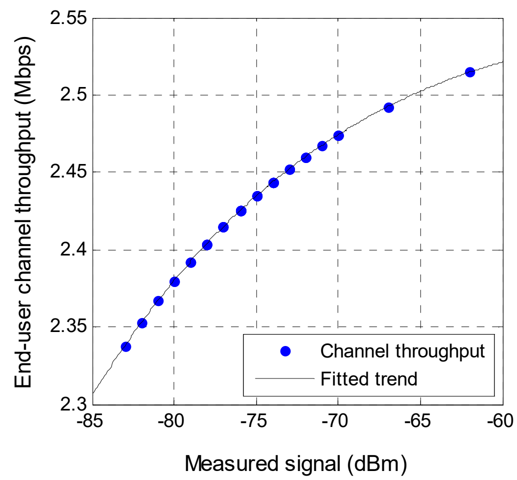


Fig. 7. Dependency of channel throughput on measured signal slots away from the BS in location 3 (NLOS case).

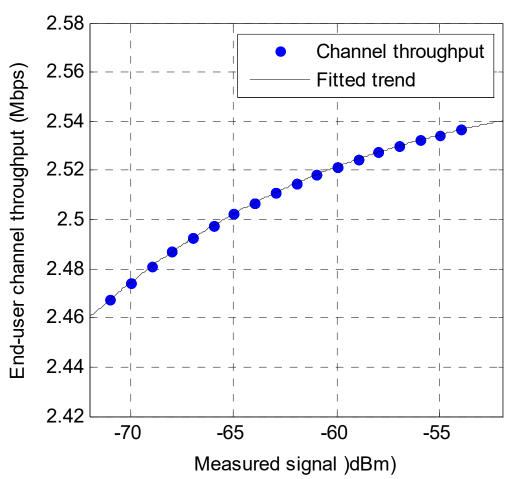


Fig. 5. Dependency of channel throughput on measured signal slots away from the BS in location 1 (LOS case).

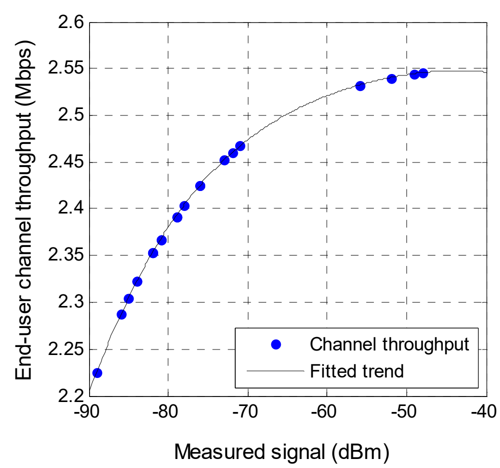
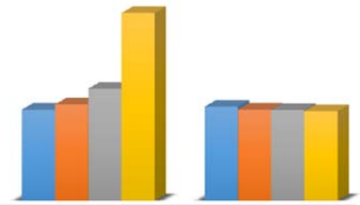


Fig. 8. Dependency of channel throughput on measured signal slots away from the BS in location 4 (NLOS case.



	Propagation loss Exponent	Mean Channel throughput (Mbps)
Location 1	2.43	2.51
Location 2	2.57	2.43
Location 2	2.99	2.42
Location 4	5.01	2.39

Fig. 9. Dependency of mean channel throughput on propagation loss exponent in locations 1 to 4 (for both LOS & NLOS).

VI. CONCLUSION

The aim of this work was to investigate the impact of end-user location and radio channel propagation environmental parameters on data throughput communication in an operational *3G* networks, with upgraded *HSDPA* technology. Based on the results, we derive the following conclusions:

- The channel throughputs are higher in areas closer to the *BS* and reduce gradually as the user move towards the cell edges. This implies that the packet drop rate on the packet data communication links increases as the user move towards the cell edges.
- A widespread fluctuation in channel throughput values were observed at each measurement slot and location, which is due to variations in the radio channel conditions such as signal quality, path losses, etc. and terrain variations.
- Results show that the data throughput performance decreases as propagation loss exponent increases. This concludes that the end-user channel throughput performance in *HSDPA* mobile broadband is very environment dependent.
- It has been found that the mean channel data throughput performance decreases as the propagation loss exponent increases. This indicates that the channel throughput performance in *HSDPA* mobile broadband is environment dependent.
- The mean channel throughputs in *Mbps* at the different *BS* locations stands at *2.51*, *2.43*, *2.42* and *2.39*, respectively.
- Hence, the influence of different radio propagation environmental variables on mobile data communication quality must be considered in the design and deployment of cellular networks, so as to provide a good end-user experience.

REFERENCES

[1] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update", 2015–2020, White Paper, February 3, 2016.

[2] J. Isabona and E.A. Odion, "A Quantification of link Average Throughput Performance in HSDPA and HSUPA by Field Measurement", Computing, Information Systems, Development Informatics and Allied Research Journal, vol. 6, No 1, pp. 49-60, 2015.

[3] A. Goldsmith. , "Wireless Communication system", 2005, New York, Cambridge University Press.

[4] M.C. Jeruchin, P. Balaban and K.S. Shanmugan, Simulation of Communication Systems, Plenum Press, New York pp.150-152, 1992.

[5] P. Gronsund, O. Grondalen,, T. Breivvik, T and Engelstad. "Fixed WiMAX Field trials Measurement and the Derivation of Pathloss Model", International Conference on Wireless and Mobile Computing, New York, NY, USA, 2007.

[6] J. Isabona and K. Obahiagbon, "A Practical-Based Radio Channel Site Survey Approach for Optimal Deployment of a Campus Wireless LAN", African Journal of Computing & ICT, Vol 6. No. 4, pp. 133-146, October 2013.

[7] M. Laner, P. Svoboda, S. Schwarz, and M. Rupp, "Users in cells: a data traffic analysis," IEEE Wireless Communications and Networking Conference (WCNC), pp. 3063–3068, 2012.

[8] U. Paul, A. P. Subramanian, M. M. Buddhikot, and S. R. Das, "Understanding traffic dynamics in cellular data networks", Proceedings IEEE INFOCOM, pp. 882–890, 2011.

[9] E. Nan, X. Chu a, W. Guo, and J. Zhang, "User Data Traffic Analysis for 3G Cellular Networks", 8th International Conference on Communications and Networking (CHINACOM), China 2013.

[10] J. Isabona, J, and D.O. Ojuh, "Radio Link Quality measurement Survey over HSDPA Radio Interface: A Holistic Technique for Efficient Networks Performance Monitoring in Wireless Communication Systems", International Journal of Advanced Research in Physical Science (IJARPS) Vol. 1, Issue 6, PP 44-55, 2014.

[11] J. Isabona, "Mean User Data Throughput Assessment from a Public UMTS/HSPA Network", Recent Trends in Electronic and Communication Systems, vol. 2. (2), pp 1-6, 2015.

[12] F. Afroz, R. Subramanian, R. Heidary, K. Sandrasegaran and S. Ahmed, "SINR, RSRP, and RSRQ measurements in Long Term Evolution Networks", International journal of Wireless and Mobile Networks, vol.7 (7), pp. 113-123, 2015.