LTE Schedulers – A Definitive Approach

Lakshmikishore Nittala, Preet Kanwar Singh Rekhi, Sukhvinder Singh Malik, Rahul Sharma

Abstract— Scheduler is the backbone of intelligence in a LTE network. Scheduler will often have clashing needs that can make its design very complex and non-trivial. The overall system throughput needs to be maintained at the best possible value without sacrificing the cell edge user experience. In this paper, authors compared different scheduler designs for voice and packet services. They explained the role of configuration parameters through simulations. These parameters control the tradeoff between the sector throughput and the fairness in system through. They explained a possible scheduler implementation.

Index Terms—LTE, Scheduler, Quality of service, GBR, Non GBR, Proportional fair.

I. INTRODUCTION

Long Term Evolution (LTE) has been introduced by 3GPP with an objective of high data rate, low-latency, better user experiences of services and packet-optimized radio access technology. LTE is also referred to as EUTRA (Evolved UMTS Terrestrial Radio Access) or E-UTRAN (Evolved UMTS Terrestrial Radio Access Network).

The LTE Scheduler will have the following major objectives:

- *Link Adaptation: It selects the optimal combination of parameters such as modulation, channel Coding & transmit schemes i.e. TM Modes as a function of the RF conditions.*
- *Rate Control: It is in charge of resource allocation among radio bearers of the same UE which are available at the eNB for DL and at the UE for UL.*
- *Packet Scheduler: It arbitrates access to air interface resources on 1ms-TTI basis amongst all active Users (Users in RRC Connected State).*
- *Resource Assignment: It allocates air interface resources to selected active users on per TTI basis.*
- *Power Control: Provides the desired SINR level for achieving the desired data rate, but also controls the interference to the neighbouring cells.*
- *HARQ (ARQ + FEC): It allows recovering from residual errors by link adaptation.*

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The Services/ Applications are broadly classified into two categories as Real time services and Non-Real time services. Real time services includes Conversational Voice, Video Phony [Conversational Video], MPEG Video [Non-Conversational Video], Real-time gaming etc.

Non-Real time services include Voice Messaging, Buffered Streaming, ftp, www, email, Interactive gaming etc.

The data transmission characteristics of these services are

- Delay tolerance
- Data Packet Size [Fixed or Variable]
- Periodic or Aperiodic data transmission
- Packet error loss rate, etc.

Some or all of these characteristics determine what kind of Packet schedulers are required at the LTE MAC to adhere to the required QoS requirements of the relevant applications.

LTE MAC supports the following three types of Scheduling

- Dynamic Scheduling
- Persistent Scheduling
- Semi-Persistent Scheduling

Dynamic Scheduling: Every TTI, MAC checks for the UEs to be scheduled, the Data Availability for each UE to be scheduled and the feedback from the UE on the Channel conditions. Based on these data, it can schedule the resources for the UE through the PDCCH. If data is not available, UE will not get scheduled. All Services can be scheduled using Dynamic Scheduling, but at the expense of the Control signalling [PDCCH Usage – a scarce resource].

Persistent Scheduling: In this case, Packets are scheduled on a fixed basis, similar to the Circuit Switched fashion. Here, it does not depend on the Channel Condition. The Resource allocation remains constant for the period of the call.

Semi-Persistent Scheduling: It is a Hybrid way of scheduling, which tries to overcome the drawbacks of the Dynamic Scheduling and the Persistent Scheduling.

This rest of the paper is organized as follows:

Section II explains persistent and semi persistent scheduling and describes why SPS is more suitable for voice services.

Section III explains different scheduler types for packet based services.

Section IV explains the configuration parameters and simulations.

Section V adds a practical scheduler implementation.

Section VI and VII provide the ‘Conclusion and Future Work’ and References authors used for preparing this article respectively.

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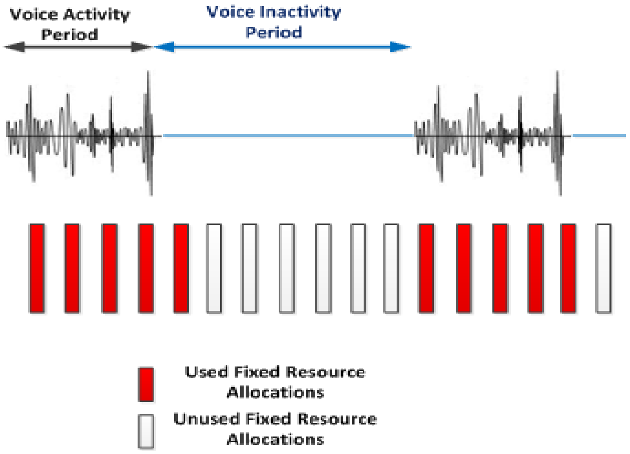
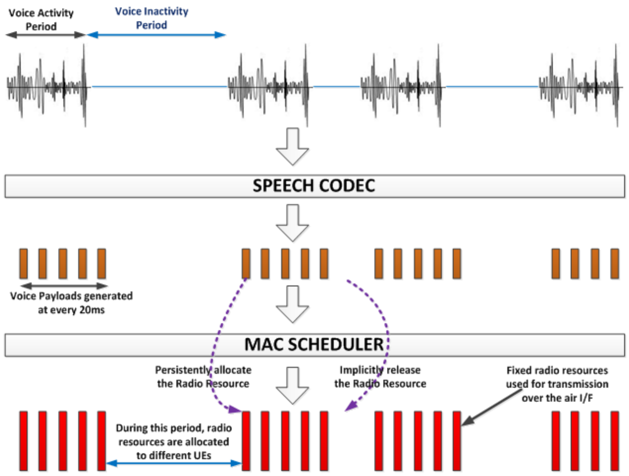
II. SEMI PERSISTENT SCHEDULING



In the above diagram conversational voice is considered for persistent scheduling. It is clear that, because of the fixed resource allocation, UE will end up in underutilizing the allocated resources, because of non-availability of the sufficient data during the persistently scheduled TTIs. Here, because the Speaker sometimes speaks and sometimes user may give pauses during the conversation, Voice activity period and Voice Inactivity period exist in the Speech data. If the Speech Codec without VAD is involved, then it sends the Voice Payload at the end of every voice frame length of 20ms during the Voice activity period and sends nothing during the Voice Inactivity period. So, the fixed resource allocations will get utilised during the Voice activity periods to transmit the received voice payloads over the air interface and it gets unused during the Voice inactivity periods, which is a critical drawback. Semi persistent scheduling addresses this drawback in a unique way.



As shown above, whenever the Voice Payloads arrive at the L2, the MAC Scheduler will activate the SPS resources and whenever there are no transmissions for few of the transmission opportunities, the SPS resources were implicitly released. Again, it gets activated, when the voice payloads arrives at the next Voice activity period. During the Voice Inactivity period and after the implicit release of the SPS resources, these radio resources will be allocated for different UEs, which are in need of it.

It is clear that, only those services, which are real time in nature, with fixed packet size payloads, and fixed periodicity of the payload arrival, can effectively and efficiently utilize the Semi-Persistent Scheduling. Such services or applications, which fulfils these characteristics are conversational voice, conversational video [only Conversational voice part of the video], and any other real time applications [Only Conversational Voice part].

III. SCHEDULERS FOR PACKET BASED SERVICES

Three kinds of schedulers are compared in this document. The RR scheduler selects and schedules UEs in a round robin manner, thereby creating an equal resource share. The disadvantage of this approach is that UEs with sub-optimal CQIs may be allocated Physical Radio Resources (PRBs), thus reducing the overall cell throughput.

The max-CQI scheduler selects the schedulable UEs based on the experienced CQI. The UEs with the highest CQI therefore become candidates for scheduling thereby increasing the overall cell throughput. The disadvantage of this approach is that UEs with lower CQI are denied scheduling instances, thus being starved for throughput and leading to degraded user experience.

The PFS is expected to strike a balance between the traditional Round Robin (RR) scheduler and the max Throughput Scheduler (also known max-CQI (Channel Quality Indicator) scheduler). The PFS scheduler performs in such a manner that it considers resource fairness as well as maximizing cell throughput (in addition to other possible performance metrics).

SCH Type	Max C/I	Round Robin	Proportional Fair (PF)
How it works	Allocates resources to the user with the instantaneous best RF conditions. UE with the best channel conditions is always prioritized	Resources are shared across users over time regardless of the RF conditions.	Sharing the cell throughput but as a function of RF conditions and bearer priorities.
Pros	Very Good Throughput	Resources shared in an equal manner	Trade-off between fairness and cell throughput.
Cons	Cell Edge UEs starved of scheduling instances leading to degraded user experience.	UEs with sub optimal CQI conditions will reduce the cell throughput	Implementation complexity and overall cell throughput will not be the highest

For a Max C/I scheduler, the Sector throughput improves while cell edge throughput drops compared to a PF scheduler where sector throughput may not be as good as Max C/I but cell edge throughput thoroughly improves.

Let us first consider the time-domain scheduling such as is the case for the non-frequency selective scheduling scheme. By using proportional fair scheduling (PFS), eNB transmits to the user m* in the nth sub frame:

$$m^*(n) = \arg \max_{m=1,2,\ldots,M} \frac{R_m(n)}{T_m(n)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

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where Rm (n), m = 1, 2, . . . , M is the data rate for the m_{th} user in the nth sub frame. Also Tm (n) is the average throughput for the m_{th} user in a past window and is updated at each sub frame according to:

$$T_m(n+1) = \begin{cases} \left(1-\frac{1}{t_c}\right) T_m(n) + \left(\frac{1}{t_c}\right) R_m(n) & m = m^*(n) \\ \left(1-\frac{1}{t_c}\right) T_m(n) & m \neq m^*(n) \end{cases} \quad \text{....... (2)}$$

where tc is the window length that can be adjusted to maintain fairness over a predetermined time horizon. The PFS algorithm schedules a user when its channel quality is better than its average channel quality condition over the time scale tc. A smaller value for tc maintains fairness over short time periods, which may be the case for delay-sensitive services. For larger tc, throughput is averaged over longer periods, which means that the scheduler can afford to wait longer before scheduling a user at its peak. On plotting 1/T (n) as a function of time for tc = 50, 100 and 200 the following observations were made. As the scheduler has little time to wait for peaks, a smaller value for tc will make the user scheduled at relatively lower peaks reducing the scheduling gains. A larger tc will allow the scheduler to wait for really high peaks and therefore results in improved system throughput at the expense of increased latency. The value of tc can therefore be selected to strike a balance between latency and throughput.

For very large tc (approaching ∞), the PFS algorithm maximizes:

$$\sum_{m=1}^{M} \log(T_m) \quad \text{....... (3)}$$

where T_m is the long-term average throughput for user m. Also, log (T_m) can be interpreted as the level of satisfaction or utility for user m. We can therefore define the PF algorithm in terms of the system utility function:

$$U(n) = \sum_{m=1}^{M} \log[T_m(n)] \quad \text{....... (4)}$$

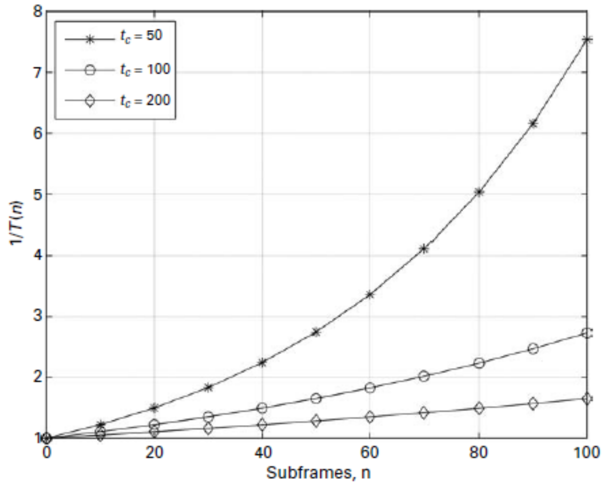

Figure 1: $1/T_n$ as a function of time for tc = 50, 100 and 200 sub frames.

eNB transmits to the user m* in the nth sub frame:

$$m^*(n) = \arg \max_{m=1,2,\ldots,M} U(n+1|m) \quad \text{....... (5)}$$

where

$$U(n+1|m) = \sum_{m=1}^{M} \log[T_m(n+1|m)] \quad \text{....... (6)}$$

where T_m (n + 1|m) denotes T_m (n + 1) given that user m is scheduled is sub frame n. Therefore the PF algorithm schedules a user in sub frame n that gives the largest instantaneous reward in the system utility function U (n).

IV. CONFIGURATIONS PARAMETERS

In this document the authors have considered α, β and γ as the configuration parameters and describe how to control the trade-off between the sector throughput and fairness in the system.

- α defines the priority of cell throughput realization, aka CQI priority. CQI is a 4-bit integer and is based on the observed signal-to-interference-plus-noise ratio (SINR) at the UE. It contains information sent from a UE to the eNB to indicate a suitable Modulation and Coding Scheme (MCS) value. There are 15 different CQI indexes defined in LTE ranging from 1 to 15 and each of these has a mapping with the modulation scheme. The MCS set by the link adaptation maps to a spectral efficiency per Resource Element (RE) as per 3GPPTS 36.213. The Spectral Efficiency per RE is a function of CQI. A higher CQI index will be given more priority.

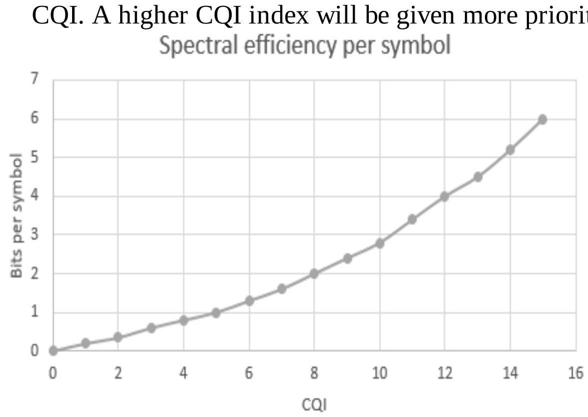

Figure 2: Spectral Efficiency

- β defines the Bit rate priority. A user with unscheduled data will be given higher priority than a user with already scheduled data. β is defined to be a measure of how much the logical channel may be under-allocated compared to the agreed bit rate during bearer establishment.
- γ defines the PDB(Packet Delay Budget) Priority. There are 9 QCI's (QOS Class Indicators) in LTE each with different PDB ranging from 50 to 300 ms. The user with lower PDB will be given higher priority. Therefore, based on the PDB, the priority for the logical channel should be updated so that the logical channel with the first packet approaching its PDB would be prioritized for scheduling.

$$\alpha + \beta + \gamma = 1 \quad \text{....... (7)}$$

The equation (7) represents the only relation between the three parameters considered.

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$\alpha = 1$ …………………………………… (8)

The equation (8) represents a Max C/I scheduler.

Testing for various parameter metrics was done with β and γ always kept at the same values and with α value being varied from 0 to 1. The testing consisted of 7identical LTE category 3 UEs placed at different radio conditions. Three UEs were placed at cell center with UEs reporting CQIs greater than 14 on an average. Two UEs were placed at an intermediate distance from the cell center, with them reporting CQI values less than 10 and greater than 8 on an average. Two more UEs were placed at cell edge radio conditions with CQIs never greater than 5. Use of a radio channel emulator was considered to achieve the above radio conditions for all the UEs. The propagation model chosen was EPA, which is pedestrian model with minimum Doppler. The results observed for PFS scheduler's sector throughput with changing α is as below:

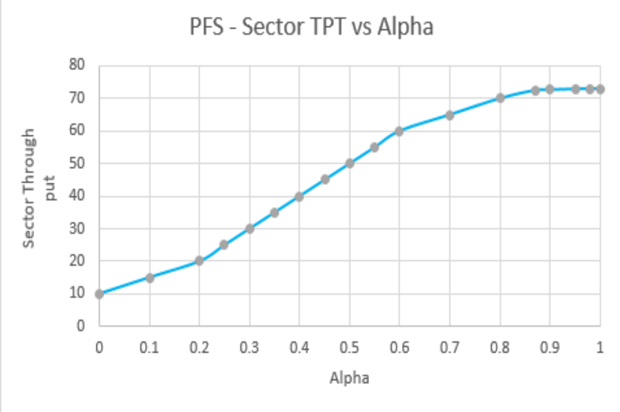


Figure 3: Sector throughput vs Alpha

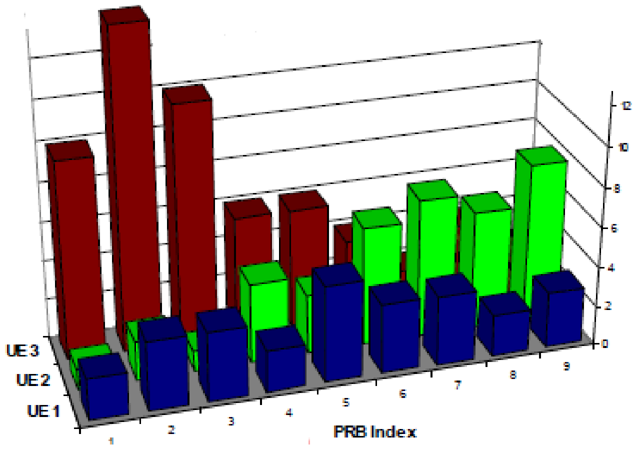
Also, the throughputs observed from $\alpha > 0.9$ were identical to the throughputs of a MAX C/I Scheduler.

V. PRACTICAL SCHEDULER IMPLEMENTATION

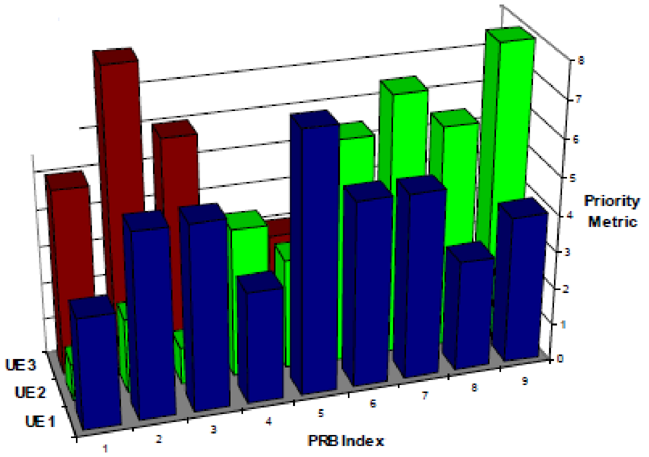
A. Conversion of QoS weight and channel information into priority metric for each users

The SINR per PRB on the UL or per resource block group (RBG) on the DL for the traffic channel is estimated from the SRS (for the UL) and the CQI report (for the DL).

UE 1
UE 2
UE 3



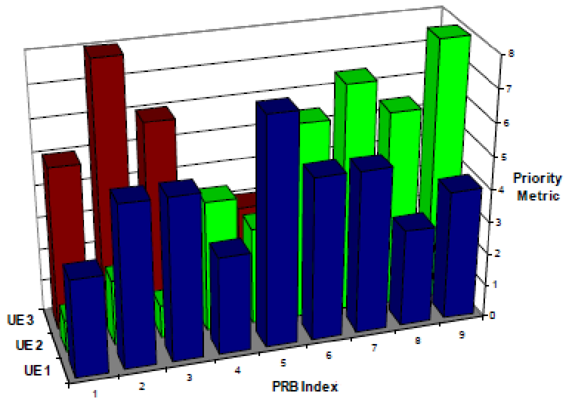
The priority metric per user is formed by mapping the SINR to an achievable rate per PRB (or RBG) using a look up table, and dividing by the average user rate and multiplying by the QoS weight. The QoS weight is used to distinguish the Dynamic Scheduler scheduling decisions across Non –GBR bearers. The GBR bearers have QCI values ranging from 1-4 and Non-GBR from 5-9.



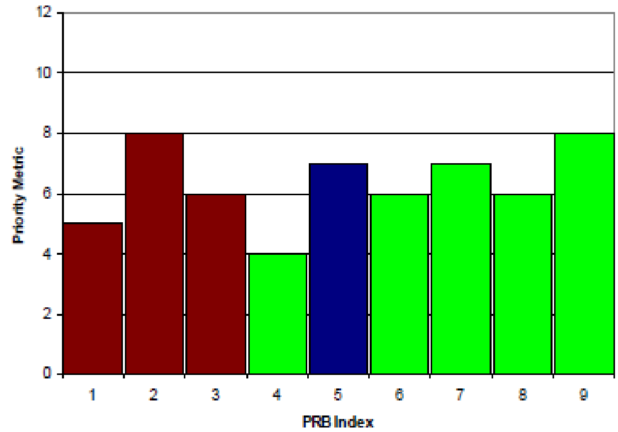
B. Identification of user with highest priority metric

For each PRB (UL) or RBG (DL) the user with the highest priority metric is identified.

UE 1
UE 2
UE 3



In DL a user is allowed to be assigned discontinuous PRBs. Each RBG is assigned to the user with the highest priority metric, which maximizes the original sum rate metric.



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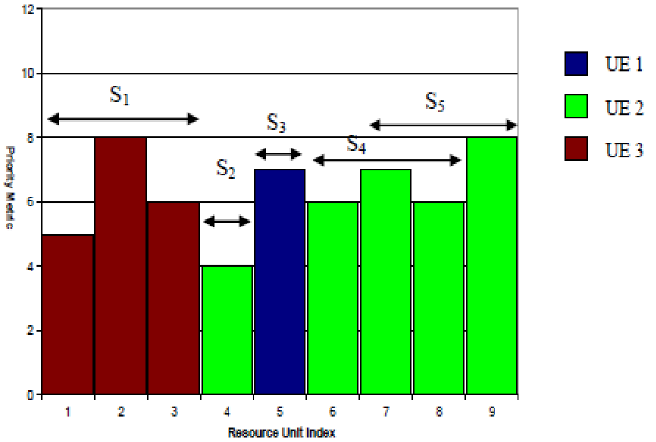
C. Maximum Priority Envelope

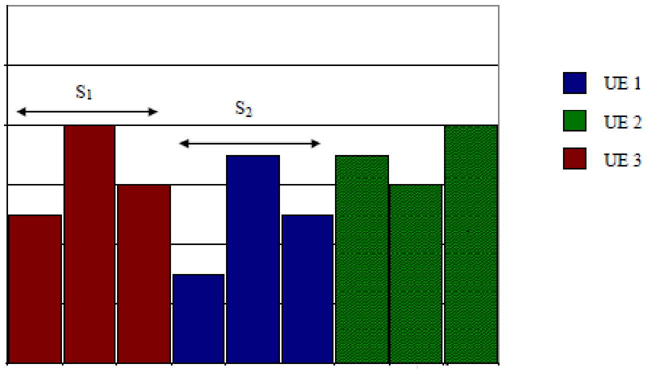
In UL the multiple access techniques is SC-FDMA. This induces constraint of contiguous PRBs and UE power headroom (PH). The sub carrier mapping in SC-FDMA maps DFT output tones to specified subcarriers for transmission and the working assumption is that the contiguous (localised) tones will be used. Power headroom indicates how much transmission power left for a UE to use in addition to the power being used by current transmission. The Maximum Priority Envelope (MPE) algorithm has been developed for UL user scheduling and resource allocation which accounts for constraints like UE PH (Power Headroom) and the contiguous PRB restriction.



In this case UE 2 has NumPRB with maximum power as 3.

D. Conclusion based on highest sum metric

Iterative process to assign contiguous sets of winning user PRBs (called envelope groups) based on the highest sum priority metric.



Assume S_5 has highest priority metric, make assignment for UE2, and update PRBs not allocated to UE2 in which it was the winner. Finally, S1 gets assigned to UE3 and S2 gets assigned to UE1.

VII. CONCLUSION AND FUTURE WORK

The simulation results indicated that the sector throughputs were identical with PFS scheduler with α =1, and for a max C/I Scheduler. However, the authors feel that the values to be configured for the three parameters considered should be specific to the site under discussion and operator configurable. All the scenarios presented in this paper were done using identical category 3 LTE devices. At all instances, 3 devices were kept at cell centre, two at intermediate distance from the cell centre and two at the cell edge conditions. It was also observed that for values of $\alpha > 0.8$, the performance did not increase as expected. For $\alpha = 0.75$, $\beta = 0.15$ and γ =0.1optimum performance was observed. Also, the test was carried out with other eNBs radiating on the same or different frequency under lab conditions. More work need to be done in identifying the range of these parameters for specific models such as rural, semi urban, urban and dense urban scenarios.

REFERENCES

[1] LTE - The UMTS Long Term Evolution from Theory To Practice 2nd Edition by Stefania Sesia , Issam Toufik, Matthew Baker
[2] Essentials of LTE and LTE-A (The Cambridge Wireless Essentials Series) by Amitabha Ghosh and Rapeepat Ratasuk
[3] 3G Evolution: HSPA and LTE for Mobile Broadband by Erik Dahlman, Stefan Parkvall, Johan Sköld and Per Beming
[4] 3GPP TS 36.211 "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation".
[5] 3GPP TS 36.213 "Evolved Universal Terrestrial Radio Access (E-UTRA) Physical layer procedures".
[6] 3GPP TS 36.321 "Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification"
[7] 3GPP TS 36.331: "Evolved Universal Terrestrial Radio Access (E-UTRAN); Radio Resource Control (RRC) Protocol Specification".

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