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Dimensioning Tracking Area for LTE Network

Rahul Sharma, Rahul Atri, Preet Kanwar Singh Rekhi, Sukhvinder Singh Malik, Mandeep Singh Arora

Abstract— Mobility management (MM) is one of the main functions in mobile networks. It aims to track the user equipment (UEs) and to allow calls, other mobile phone services to be delivered to UEs. For any mobility protocol there are two separate problems to be solved. One is location management (or sometimes called reachability), which keeps track of the positions of a UE in the mobile network. The other one is handover management (or sometimes called session continuity), which makes it possible for a UE to continue its sessions while moving to another cell and changing its access point. This document focuses on the location management problems. Tracing UEs in a mobile network is the key task in location management. Tracking Area (TA) in LTE is a logical grouping of cells in a network. TA is almost the same concept as the Location Area (LA). In configuring TAs, a key consideration is to minimize the total amount of signaling overhead.

Index Terms—LTE, Tracking Area, Paging Capacity TA list.

I. INTRODUCTION

Long Term Evolution (LTE) has been designed to support only packet-switched services. It aims to provide seamless Internet Protocol (IP) connectivity between User Equipment (UE) and the packet data network (PDN), without any disruption to the end user’s applications during mobility

The term “Long Term Evolution” encompasses the evolution of the Universal Mobile Telecommunications System (UMTS) radio access through the Evolved UTRAN (E-UTRAN)

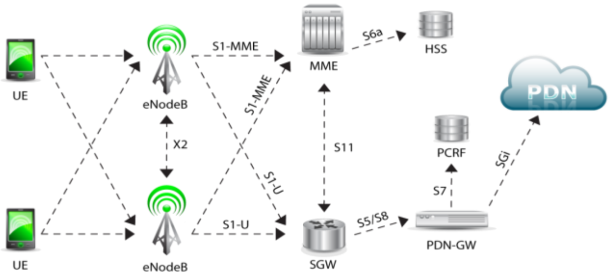

Figure 1: LTE Architecture and Its Interfaces

It is accompanied by an evolution of the non-radio (Core Network) aspects under the term “System Architecture Evolution” (SAE), which includes the Evolved Packet Core (EPC) network.

At a high level, the network is comprised of the Core Network (EPC) and the access network E-UTRAN. The Core Network consists of many logical nodes. The core network in LTE is called Evolved Packet Core (EPC) which is responsible for the overall control of the UE and establishment of the bearers.

The main logical nodes of the EPC are PDN Gateway (PGW),

Serving Gateway (S-GW), Mobility Management Entity (MME), Home Subscriber Server (HSS), Policy Control and Charging Rules Function (PCRF)

The access network is made up of essentially just one node, the evolved NodeB (eNodeB), through which Connects UE to the network.

Each of these network elements is interconnected by means of interfaces that are standardized in order to allow multi-vendor interoperability. This gives the possibility to source different network elements from different vendors.

II. GUIDELINES FOR DIMENSIONING AND PLANNING TRACKING AREA (TAS)

Dimensioning aims to find a suitable number of eNodeBs to be included in a TA list.

Planning includes determining TA borders and configuring TA lists.

A. Key Terms

The following terms are used in this document:

Blocked page: A blocked page is a page that cannot be transmitted over the air interface at the first valid Paging Occasion (PO) due to lack of resources.

Page: The message sent by the Mobility Management Entity (MME) to the User Equipment (UE) during paging.

Paging: The procedure in which the MME notifies an idle UE about an incoming data connection. The procedure includes sending a paging message over the S1 Application Protocol (S1-AP) and the air interface.

Paging capacity: The average number of pages per second that a node can handle. Paging capacity incorporates various margins to manage conditions like traffic fluctuations.

Paging Frame (PF): The radio frames where UE paging can take place.

Paging load: The fraction of resources required for paging.

Paging Occasion (PO): The sub frames where UE paging can take place. Paging record Pages to different UEs can be multiplexed in the same Radio Resource Control (RRC) paging message. A paging record is the information associated with one of those pages.

B. Tracking Areas, Code and Lists:

Tracking Area: A Tracking Area corresponds to the Routing Area (RA) used in

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Rahul Sharma B.Tech in Electronics and Communication Engineering from GGSIPU.

Rahul Atri B.Tech in Electronics and Communication Engineering in 2010 with Honours. Having about 4 years of experience in LTE development industry in different fields i.e. Protocol testing,

Preet Kanwar Singh Rekhi B.Tech in Electronics and Communication Engineering from GGSIPU.

Sukhvinder Singh Malik B.E. in Electronics and Communication Engineering from MDU Rohtak .

Mandeep Singh Arora B.Tech in Electronics and Communication Engineering from GGSIPU.

Wideband Code Division Multiple Access (WCDMA) and GSM/Edge Radio Access Network (GERAN). The TA consists of a cluster of eNodeBs having the same Tracking

Tracking Area Code (TAC): The TA provides a way to track UE location in idle mode. TA information is used by the MME when paging idle UE to notify them of incoming data connections.

Tracking Area Lists: In LTE, the MME provides the UE with a list of tracking areas where the UE registration is valid. When the MME pages a UE, a paging message is sent to all eNodeBs in the TA list. The concept of TA lists is shown in the following figure:

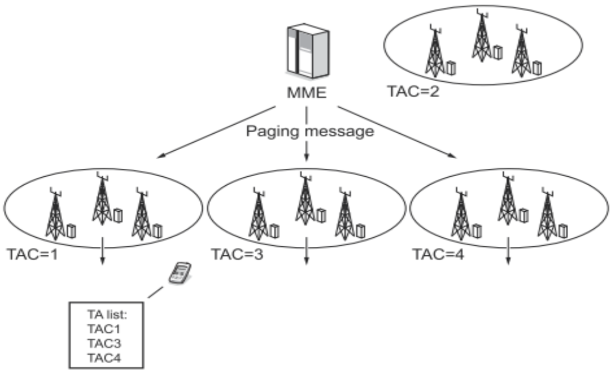


Figure 2: TAC and TAC list

The MME sends the TA list to the UE during the TA update procedure. TA updates occur periodically, and when a UE enters a cell with a TAC not in the current TA list. The TA list makes it possible to avoid frequent TA updates due to Ping-Pong effects along TA borders. This is achieved by including the old TA in the new TA list received at TA update.

C. *Tracking Area Dimensioning*

While Dimensioning the TA/TAL below mentioned two criteria's have to be taken into consideration:

A small number of eNodeBs in a TA list may require frequent TA updates. Frequent updates increase the MME load and UE battery consumption. In addition, frequent updates may reduce the paging success rate, because the UE cannot respond to paging during the TA update procedure.

While, if we increase the number of eNodeBs in the TA list, the TA update frequency is reduced. The drawback of adding more eNodeBs to the TA list is that the paging load increases. The upper limit of the number of eNodeBs in a TA list is determined by the paging capacities of the MME and eNodeB.

Note** TA planning is the task of configuring TAs and TA lists so that area excessive TA updates signaling are avoided.

III. PAGING

Paging is used primarily to notify user equipment in idle state about incoming data connections. This document provides a summary of the paging function with emphasis on the parts relevant for TA dimensioning.

A. Paging Procedure

The MME is the core node responsible for UE paging. When the MME receives a downlink data notification message from the Serving Gateway (SGW), the MME sends an S1-AP paging message to all eNodeBs in the TA list. When the S1-AP paging message arrives at the eNodeBs it is queued until the valid PO occurs. The message is then transmitted over the air interface using resources on the Physical Downlink Control Channel (PDCCH) and the Physical Downlink Shared Channel (PDSCH).

The Downlink Control Information (DCI) containing the scheduling assignment for the paging message is transmitted over PDCCH. The scheduling assignment is common for all UE monitoring a certain PO.

The following figure illustrates the paging procedure:

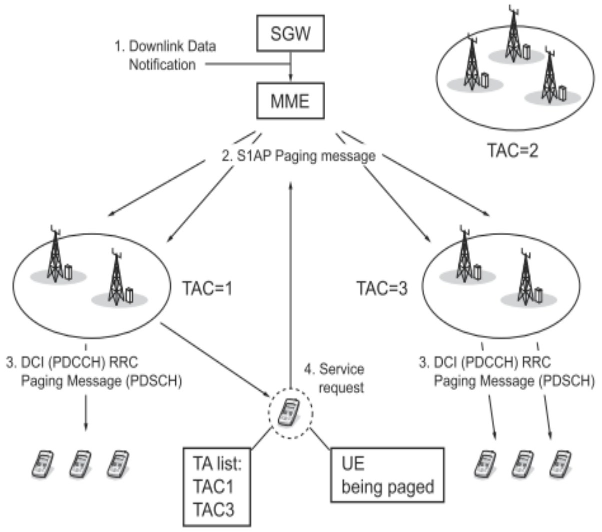


Figure 3: Paging Procedure

When UE monitoring the PO detects the scheduling assignment, the UE demodulates and decodes the RRC paging message sent on the PDSCH. The RRC paging message contains information about the exact identity of the UE being paged. UE that do not find their identities in the RRC paging message discard the data and sleep according to the DRX cycle. A UE recognizing its identity sends a service request to the MME. Several UE may be addressed in the same RRC paging message.

If the MME does not receive the service request within T3413 seconds, it resends the S1-AP paging message. In the initial attempt the message is sent to the eNodeBs within the same TA list. The maximum number of transmission attempts is specified by parameter N3413. When paging messages arrive in the eNodeB, the RRC layer tries to send the paging message in the first valid PO. If it is impossible to send the paging message in the first PO because of blocking, for example, attempts are made to send the paging message in subsequent POs according to the DRX cycle.

The RRC layer tries to send the paging message during a period specified by the parameter paging Discard Timer, after which the paging message is discarded.

It is recommended that the paging Discard Timer be set equal to or smaller than T3413. To guarantee at least one retransmission attempt by the RRC layer, the paging Discard Timer must be set to a larger value than the DefaultPagingCycle.

B. Paging Frames and Paging Occasions

UE paging is possible only in certain frames and sub frames. These are referred to as terminologies are PF (Paging Frame) and PO (Paging Occasion).

- Paging Occasion (PO) is a sub frame where there may be P-RNTI transmitted on PDCCH addressing the paging message.
- Paging Frame (PF) is one Radio Frame, which may contain one or multiple Paging Occasion(s).

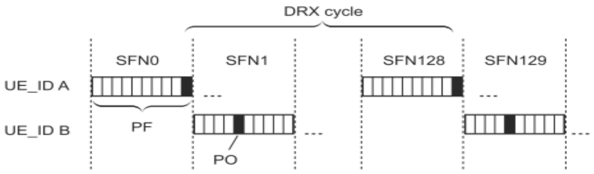


Figure 4 : Paging Frames and occasions

LTE has two timing units:

- Timing Unit in Frame scale (SFN: System Frame Number).
- Timing unit in sub frame level (Sub frame Number).

In same way for the paging cycle, PF (Paging Frame) + PO (Paging Occasion) let us know the exact timing when UE has to wake up to catch the paging message being sent to it.

The default Paging Cycle determines the Discontinuous Reception (DRX) cycle, that is, how frequently a UE monitors POs. A shorter DRX cycle decreases the time for paging but increases battery consumption.

C. Calculations for Paging Frame and Paging Occasions:

The following Parameters are used for the calculation of the PF and PO:

T: Paging cycle (DRX cycle of the UE). T is determined by the shortest of the UE specific DRX value, if allocated by upper layers, and a default DRX value broadcast in system information. If UE specific DRX is not configured by upper layers, the default DRX value is applied,

T = Min (PagingDRXCycle, DefaultPagingDrxCycle)

Default paging cycle is one of values in {32, 64, 128,256} radio frames.

N: min (T, nB)

Ns: max (1,nB/T)

UE_ID: IMSI mod 1024

nB: 4T, 2T, T, T/2, T/4, T/8, T/16, T/32

i_s: index which points to PO from sub frame pattern, it is calculated later on this document.

Let us calculate PF occasions first, it is calculated by:

SFN mod T= (T div N)*(UE_ID mod N) -------------------- (1)

So let us take an example

Transmitted in SIB2: nB = T / 4, DefaultPagingCycle = 64

From S1-Paging Message: PagingDRX= 128

UE Index from S1 Paging: UE_ID = 0x0115 = (0000 0001 0001 0101)

After Removing 6 LSBs which makes (0000 0001 00 = 4)

The above UE Index is in general UE Identity Mod 1024 which means, results only occupies 10 Bits Only. So, above we Removed 6 LS bits.

Thus for the above information,

As, T = Min (PagingDRXCycle, DefaultPagingDrxCycle) = Min (128, 64) = 64

nB = T/4 = 64/4 = 16

And hence N can be calculated as:

N = min (T, nB) = Min (64, 16) = 16

nB	4T	2T	T	1/2 T	1/4 T	1/8 T	1/16 T	1/32 T
N	1	1	1	1/2	1/4	1/8	1/16	1/32

UE_ID = 4 (From above Steps derived from S1 Paging Message).

Now putting all the values in Eqn1 (SFN mod T= (T div N)*(UE_ID mod N)) we will get,

RHS => (T Div N) * (UE_ID mod N) = (64 Div 16) * (4 Mod 16) = 4 * 4 = 16

LHS => SFN Mod T = SFN Mod 64 = 16

So, PF values could be anything where SFN = (64 * i) + 16 (I = 0 to N but SFN <= 1024)

Thus Values PF can be any of 16, 80, 144, 208, 272, 336, 400, 464, 528, 592, 656, 720, 784, 848, 912, 976, 1040, 1104, and 1168.

Let us now calculate PO:

As nB is T/4 for our example, T = 64,

Ns= max (1, nB/T) = max (1, 16/64) = 1

nB	4T	2T	T	1/2 T	1/4 T	1/8 T	1/16 T	1/32 T
Ns	4	2	1	1	1	1	1	1

i_s = floor (UE_ID/N) mod Ns

Thus, i_s = floor (4 / 16) mod 1 = 0

For TDD:

Ns	PO when i_s=0	PO when i_s=1	PO when i_s=2	PO when i_s=3
1	0	N/A	N/A	N/A
2	0	5	N/A	N/A
4	0	1	5	6

As we can see from the table,

When Ns = 1, there can be only one paging occasion (only one sub frame where paging message is carried) within a Paging Frame and the sub frame number is 0

When Ns = 2, there can be two paging occasions (two sub frames where paging message is carried) within a Paging Frame and the sub frame number is 0 and 5.

When Ns = 4, there can be four paging occasions (four sub frames where paging message is carried) within a Paging Frame and the sub frame number is

0, 1, 5 and 6.

IV. TA DIMENSIONING

TA planning is the task of configuring TAs and TA lists so that area with excessive TA updates signaling are avoided.

The process of TA dimensioning contains two main tasks:

- TA dimensioning for the MME
- TA dimensioning for the eNodeB

These steps can be done sequentially or in parallel. The output of the tasks is the total number of eNodeBs suitable to include in a TA list. For information on the number of eNodeBs to include per TA, and the number of TAs to include in a TA list,

An overview of the process for TA dimensioning is shown in the following figure:

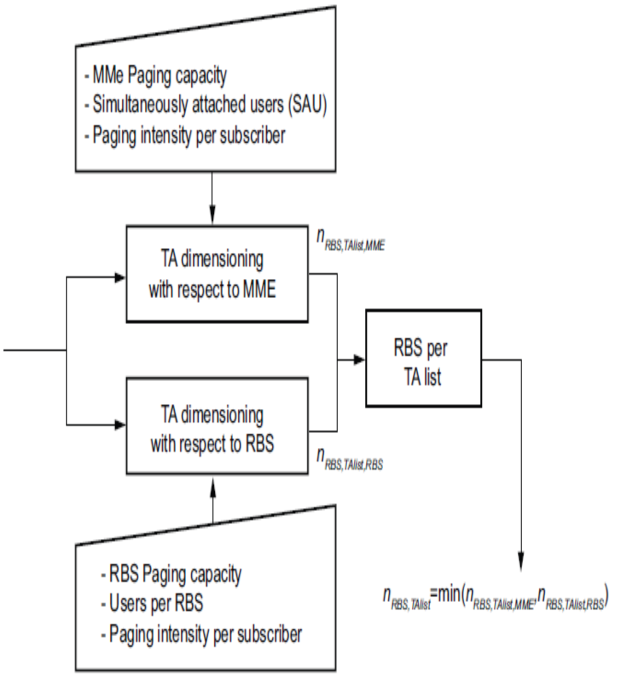


Figure 5: Overview of Process for TA Dimensioning

Input Data:

The following input data is required in the TA dimensioning process:

Paging capacity of the MME,

- Paging capacity of the eNodeB,
- Paging intensity per subscriber (during busy hour)
- Number of Simultaneously Attached Users in an MME during busy hour
- Average number of subscribers per eNodeB during busy hour.

MME Paging Capacity, CMME: MME paging capacity depends on the number of SCTP/S1 boards in the MME. This is capacity of individual S1-MME link.

As an example, an MME configured with 5 SCTP boards has a paging capacity of 1500 x 5 = 7500 outgoing pages/s.

eNodeB Paging Capacity, CeNodeB: The eNodeB paging capacity depends partly on Central Processing Unit (CPU) constraints, and also on the amount of resources that the paging traffic is allowed to consume. The more resources used for paging, the higher the paging capacity

The following criteria are used when calculating the eNB paging capacity:

CPU load (Ccpu): The consumption of CPU resources due to paging traffic must be reasonably low for the CPU to handle other tasks.

PDSCH load (CPDSCHLoad): The consumption of PDSCH resources due to paging must be reasonably low. Paging traffic has higher priority than user data and a high paging traffic may reduce downlink capacity and achievable bit rates.

Blocking (CBlocking): The fraction of paging records being blocked due to PDSCH must be low. Blocking introduces delays in the paging procedure and in the set-up of the data connection.

PDCCH load (CPDCCHLoad): The consumption of PDCCH load due to paging must be reasonable low. Paging traffic has higher priority than user data, and high paging traffic may reduce the PDCCH ability to carry other signaling traffic such as downlink scheduling assignments and uplink scheduling Grants.

The following equation describes how to calculate the paging capacity for each of the four criteria. The total eNB capacity is given as the minimum of the four capacity figures:

CeNodeB = Min (Ccpu, CBlocking, CPDSCHLoad, CPDCCHLoad)

Paging Capacity and CPU Load: Incoming pages are handled by CPUs in the eNB per second. To ensure that paging traffic does not have an adverse effect on the ability of the CPU to handle other tasks, paging traffic must be reasonably low.

Paging Capacity and PDSCH Load: To calculate the paging capacity in relation to PDSCH load, the first step is to consider the average number of scheduling blocks required to convey a page over PDSCH. The exact number depends on the number of paging records included in the RRC paging message.

Now using the cost of conveying one paging message, The PDSCH paging load L(PDSCH)can be expressed as a function of paging intensity,

L (PDSCH) Load =Sn* Ipage/100*Sn (Frame)

Where,

Sn (no of Scheduling blocks required to send Paging message over PDSCH) which depends on number of symbols for used for PDCCH.

Sn= 2.75+0.24(no of symbols for PDCCH – 1)

Ipage is the paging intensity, that is, the average number of incoming pages to the RBS per second.

Sn (Frame) is the available number of scheduling blocks per frame.

$$C_{PDSCHload} = \frac{100 n_{SB,frame} L_{PDSCH,max}}{2.75 + 0.24\left(n_{PDCCHsymb} - 1\right)}$$

Where L (PDSCH) is the tolerable PDSCH load due to paging.

Paging Capacity and Blocking: As mentioned earlier, the number of paging records that can be transmitted during a sub frame is limited by parameter maxNoOfPagingRecords.

$$P_{blocking,max} = 1 - \frac{R_{max} - e^{-C_{blocking,PO}} \times \sum_{R=0}^{Rmax} (R_{max} - R) \frac{C^{R}_{blocking,PO}}{R!}}{C_{blocking,PO}}$$

$C_{blocking,PO}$	is the paging capacity in relation to blocking expressed as pages per PO.
$P_{blocking,max}$	is the tolerable probability for a page being blocked.
R_{max}	is the value of `maxNoOfPagingRecords`.

The value to use for L (PDSCH) is determined by the operator. As a general Rule should not exceed 5%.

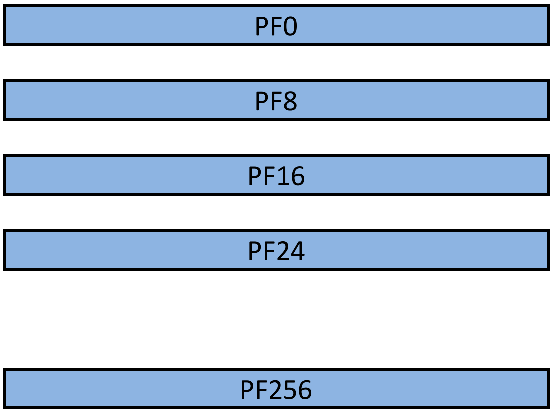
To calculate this we need to fond PF and PO's according to settings of our network's current configurations.

From Equation1 (SFN mod T= (T div N)*(UE_ID mod N)), we can calculate PF,

T = 256, nB = T/8,

It comes out to be SFN mod 256 = 32; hence the PF periodicity will be 32, 288,544…..so on, this is an example for one UE with UE_ID mod N = 4, we can multiple combinations like this for different UE_IDs,

For multiple UEs, Maximum number of PFs can be multiples of T/8 (T= 256) as shown in figure, thus we have maximum of 32 PFs.

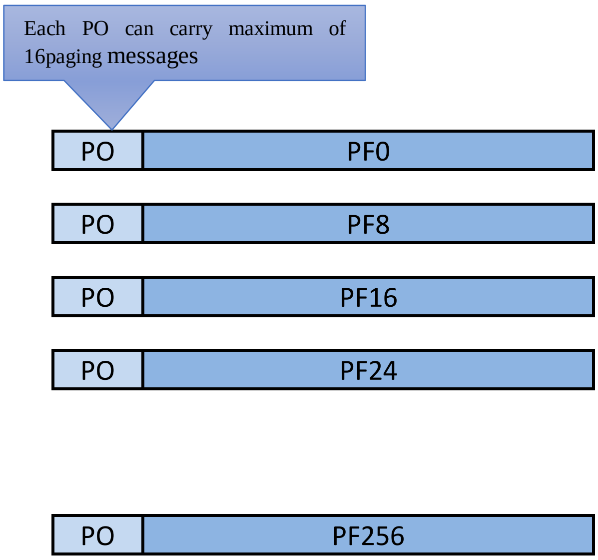


Now as in our example we can similarly calculate PO occasions, depending on values of Ns and i_s we can calculate POs, maximum for every PF we can have 4 POs. For our system no of POs for one PF is 1.

Now we know we have 32PFs and 32POs, each PO can have 16Paging messages thus 32Pos will have 512messgages as in our case T is 256 it means total of 256*10ms.

So we have 512 paging messages in 2.56seconds

And calculating for 1 hour we have 512/2.56 *3600= 720,000 paging messages. Hence per second 720000/3600 = 200 pages/second, maxNoOfPagingRecords.



Paging Capacity and PDCCH Load: A common scheduling assignment for the paging message is sent on PDCCH. Assuming that the pages arrive according to a Poisson process, the probability of a scheduling assignment to send is given by: Probability of scheduling assignment

$$P_{SA} = 1 - e^{-I_{page,PO}}$$

Since the scheduling assignment needs to reach all UEs in the cell (including those located in poor radio conditions), it is transmitted using 8 Control Channel Elements (CCEs). The average number of CCEs required for paging traffic per frame is expressed as:

$$n_{CCE,PO} = 8n_{PO,frame}\left(1 - e^{-I_{page,PO}}\right)$$

The PDCCH load is calculated by comparing the number of CCEs used for transmitting the scheduling assignment per frame with the total number of CCEs per frame. The final equation for PDCCH capacity is written as:

$$C_{PDCCHload} = -100n_{PO,frame} \times \ln\left[1 - \frac{n_{CCE,frame}L_{PDCCH,max}}{8n_{PO,frame}}\right]$$

LPDCCH: is the tolerable PDCCH load due to paging

Based on all above criteria we can find, eNodeB paging capacity

CeNodeB = Min (Ccpu, CBlocking, CPDSCHLoad, CPDCCHLoad),

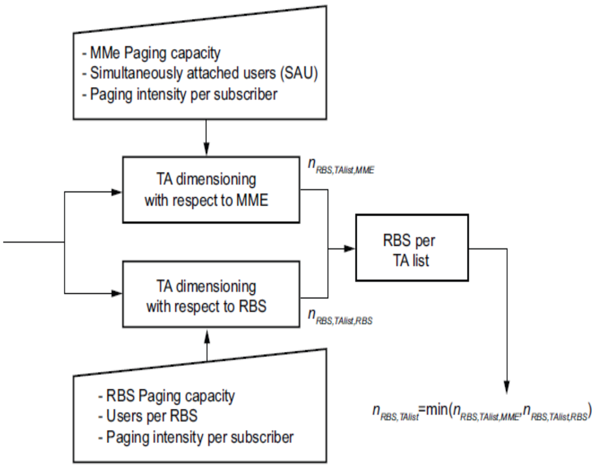
In our case CBlocking has the minimum value. Hence CeNodeB = 200

A. Maximum number of eNBs in TAL

TA Dimensioning with respect to MME

- MMME paging Capacity (can be calculated, as mentioned earlier), CMME
- Simultaneously attached users, SU (AU)
- Paging Intensity per subscriber
- Number of eNodeBs per TA list in relation to MME paging capacity:
- NeNodeB(MME) = CMME /

SU(AU)*Paging Intensity per subscriber



TA Dimensioning with respect to eNodeB

- eNodeB paging capacity (calculated above)
- Users per eNodeB, U(eNodeB)
- Paging intensity per eNodeB

Number of eNodeBs per TA list in relation to eNodeB paging capacity

NeNodeB (eNodeB) = CeNodeB/ U (eNodeB)*Paging Intensity per subscriber

Hence, Maximum number of eNodeBs in TAL = min (NeNodeB (MME), NeNodeB (eNodeB))

V. CONCLUSION

The information in this paper helps in dimensioning the number of eNodeBs for a tracking area minimizing the signaling overhead and thus, helping in targeting location management problems. It describes the basic terminologies in EPC and presents complete calculations for Tracking Area lists.

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AUTHOOR PROFILE

Rahul Sharma B.Tech in Electronics and Communication Engineering from GGSIPU in 2011 with Honors. Having 3 years of experience in LTE development industry in different fields i.e. LTE Physical layer procedures, Signal processing chain and Integration with upper layers etc.

Rahul Atri B.Tech in Electronics and Communication Engineering in 2010 with Honours. Having about 4 years of experience in LTE development industry in different fields i.e. Protocol testing, Quality Assurance etc.

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Preet Kanwar Singh Rekhi B.Tech in Electronics and Communication Engineering from GGSIPU in 2010 with Honours. Having about 4 years of experience in LTE QA/QC industry in different fields like Protocol, Performance, and Radio etc.

Sukhvinder Singh Malik B.E. in Electronics and Communication Engineering from MDU Rohtak in 2010 with Honours. Having about 4 years of experience in LTE domain in different fields i.e. Radio, Protocol testing, Quality Assurance etc.

Mandeep Singh Arora B.Tech in Electronics and Communication Engineering from GGSIPU in 2010. Having about 4 years of experience in EMS/NMS development, Protocol and Simulations.