TRACKING AREA RECONFIGURATION AND OPTIMIZATION FOR 5G CELLULAR NETWORKS

A DISSERTATION

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By

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CANDIDATE'S DECLARATION

I declare that the work presented in this dissertation with title "**Tracking Area Reconfiguration and Optimization for 5G Networks**" towards the fulfillment of the requirement for the award of the degree of **Master of Technology** submitted in the **Department of Electronics and Communication Engineering**, **Indian Institute of Technology Roorkee**, India. It is an authentic record of my own work carried out under the supervision of **Dr. P.M. Pradhan**, Assistant Professor, Department of Electronics and Communication Engineering, IIT Roorkee.
The content of this dissertation has not been submitted by me for the award of any other degree of this or any other institute.

DATE : .... SIGNATURE:

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CERTIFICATE

This is to certify that the statement made by the candidate is correct to the best of my knowledge and belief.

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Abstract

5G is expected to accommodate exceptional services beyond current cellular systems. The three main use cases envisioned for 5G networks are enhanced Mobile Broadband, massive Machine Type Communication and Ultra Reliable and Low Latency Communication. The enormous competition and the increasing number of UEs in the telecommunication market have garnered attention towards the necessity of optimized and cost-efficient network. Tracking the position of UEs while minimizing the signalling cost is a key challenge that needs to be addressed for the upcoming 5G networks. Tracking area (TA) is a term used for the assemblage of cells in long term evolution (LTE) network. Planned distribution of TAs, depending on the mobility pattern of UEs, is a technique used to optimize the signalling overhead, and plays a vital role in utilizing the resources efficiently. Compared to the earlier generations of cellular networks, 5G networks will have more flexible configuration of TAs as it will utilize the concept of TA list, given in 3GPP release 12. One of the objectives of 5G mobile network is to cope up with an ever increasing number of UEs. This thesis discusses TA reconfiguration for 5G network using game theory, and proposes an optimal solution for reducing the signalling overhead of the network.

In order to satisfy the 5G requirements, heterogeneous radio access technologies (RATs) have been proposed. To use the RAT efficiently, massive connectivity of devices has been proposed in 3GPPP Release 15. For the earlier phase, non-standalone architecture has been proposed in which existing 4G LTE infrastructure will be used. To have a full 5G network coverage stand alone architecture has been proposed in 3GPP release 15 for which low-cost and low-power small base-stations (microcells) will be deployed, and these power supplied active nodes will form the clusters as per proposed algorithm. Increasing the number of devices will give rise to signalling overhead issue consisting of TA update (TAU) and paging overhead. This thesis proposes a method to reduce the signalling cost using clustering algorithm and the unification of both the layers (4G and 5G).

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Abbreviations

4G	Fourth Generation
5G	Fifth Generation
UE	User Equipment
TA	Tracking Area
TAL	Tracking Area List
RRH	Remote Radio Head
RRU	Remote Radio Unit
NR	New Radio
EUTRAN	Evolved UMTS Terrsetial Radio Access Network
UMTS	Universal Mobile Telecommunicatios System
QoE	Quality of Experience
AR	Augmented Reality
VR	Virtual Reality
NG	Next Generation
NGCN	Next Generation Core Network
ENDC	Evolved UTRAN New Radio Dual Connectivity
IoT	Internet of Things
LTE	Long Term Evolution

Symbols and Notations

Notation	Description
$\hat{U}$	Set of UEs in the network
$\hat{L}$	Set of TAs in the network
$\hat{c_m}$	Number of cells (eNodeB) in a TA
α_u	Probability that UE gets paged during a period
β_u	Probability that UE moves from one TA to another
γ_u	Mobility and paging ratio of UE
Γ_i	Set of possible TALs that can be assigned to UEs in a TA
$\digamma_i$	Sorted elements of TAL
S	Matrix that ensures the mapping between TAs and TALs in the network
$P_i(j)$	Probability of selecting TAL in a TA
Γ	Set of all possible TALs in the network
y_{uv}	Number of handover between TAs
O^{TAU}	Overhead of one TAU operation
O^{paging}	Overhead of one paging message
μ_i	Exponential distribution rate of the sojourn time of UEs in a TA
λ	Exponential distribution rate of interarrival time between two consecutive calls

Chapter 1

Introduction

1.1 Motivation

In the past few years, the demand for mobile gadgets has grown up sharply, as result of which internet services have become a common need for most of the individuals [1]. Alongside expanding information rates and enhanced scope, this pattern empowers novel utilization of cellular techniques that were considered impractical in past. Of all the services, the Internet of Things (IoT) is very conspicuous [2]. The possibility of a IoT depends on the forecast that in two or three years, the web won't just be utilized by individuals, but it will aim to develop a platform for a wide range of machines and gadgets [3]. Expecting that every individual will be using a bunch of IoT empowered gadgets, the upcoming age of cell frameworks will be looked with a greatness of bigger number of subscribers [1,4]. Furthermore, this will present an expansive assortment of new necessities, e.g. regarding mobility, information rates, low latency, etc.

Fourth generation (4G) systems were streamlined to give high information rates and dependable services to variety of users [1]. As shown in Fig. 1.1, cell frameworks of the fifth generation (5G) will confront more differing application necessities: the desire of faster information rates surpasses the capacities of 4G; battery-driven transmission sensors require very-low power utilization [5-7]; and control applications demand for short reaction times [8]. Over the last decade, there has been tremendous growth in cellular communication, especially mobile broadband networks. Long term evolution (LTE) is a term basically used for 4G that aims to improve mobile communication with an emphasis on mobile broadband [9]. LTE offers new features that improve network efficiency and performance. The planning process in mobile communication system involves tracking

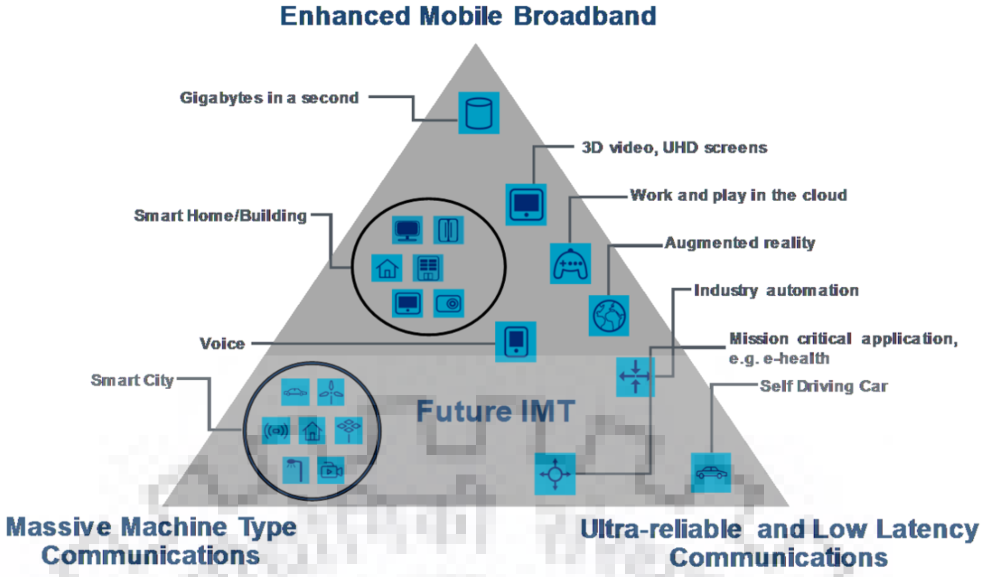


Fig. 1.1. 5G use scenarios [1]

and management of user equipment (UE). A UE can transmit or receive a call anywhere, at any time in the network [1–25]. Mobility management provides means to find the position of UEs and deliver services (such as calls, SMS etc.) to UEs [10]. The two aspects of mobility management are location management (also called reachability) and handover management (also called session continuity) [11]. Location management keeps track of UEs in mobile networks so that when needed, mobile phone services can be delivered to UEs [12].

Fig. 1.2. Tracking areas [2]

In conventional tracking area (TA) design, cells form disjoint sets of TAs as shown in Fig. 1.2 [2]. TA is a reasonable combination of nodeBs (NBs) in a network, and is used to track and locate (page) UEs. Handover management enables session continuation when UEs change cells [13]. This thesis focuses on location management aspect of mobility management in LTE and beyond networks. One of the key tasks of location management is to keep track of UEs in the network. 3GPP Release 12 has given the idea of the TA list (TAL) [2,9]. TAL contains two or more TAs so as to make the network more flexible, and hence reduce the overall cost of the network. In 3GPP Release 12, a network is allowed to have upto 15 TAs in a single TAL [3]. As compared to conventional TA, usage of TAL concept leads to reduction in signalling cost [13].

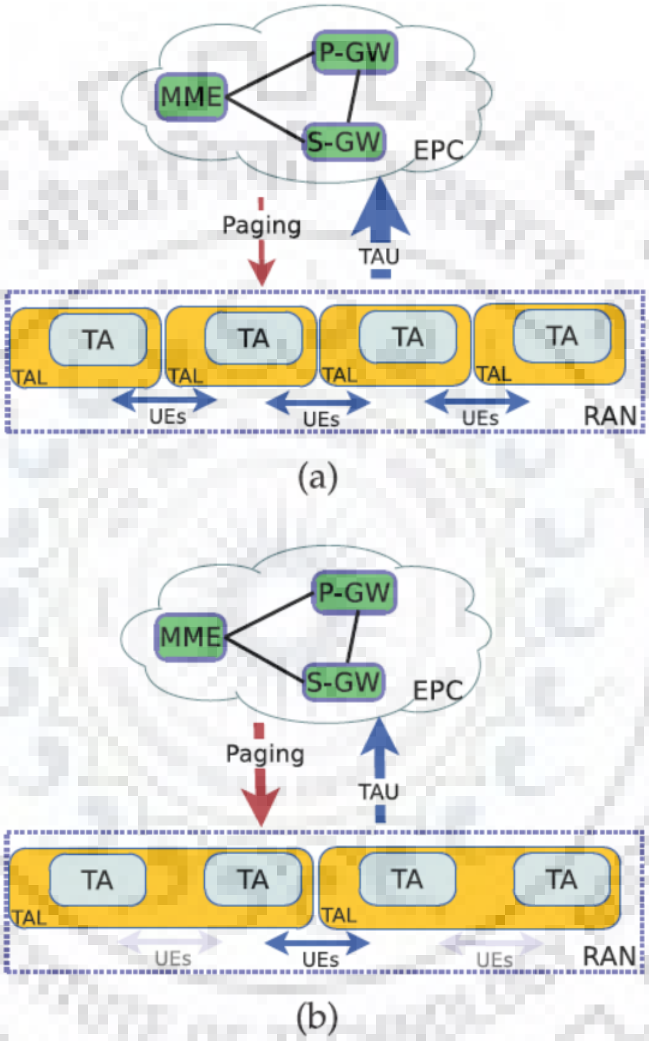


Fig. 1.3. Trade-off between cost incurred towards TAU and paging (a) Each TAL includes one TA; (b) Each TAL includes two TAs [3]

The overall signalling cost for a given network comprises of costs incurred towards tracking area update (TAU) and paging [14]. As shown in Fig. 1.3, there is a trade-off between these two conflicting metrics. Considering the first scenario in Fig. 1.3(a), where each TAL includes only one TA, it is easy to locate the UEs in this case, and therefore paging cost is low. However, cost incurred towards TAU is high as a UE might cross the boundary and cause signalling overhead. Similarly, considering the second scenario shown in Fig. 1.3(b), where each TAL includes two TAs, cost incurred towards TAU is low compared to first scenario, but paging cost is more [1,15]. Therefore, the objective is such that to lessen the overall signalling cost. As the number of UEs will increase in future while cell size will reduce in 5G network, the optimization of signalling cost is necessary. In this thesis, random walk model is considered for mobility pattern of UEs in a 5G network. Based on the mobility pattern of UEs, cells (nodes) form a new cluster or TA so as to reduce the overall signalling cost.

1.2 Thesis Contribution

The major contribution of this thesis are as follows:

- Localization of the UEs to lessen the paging cost of the network using clustering algorithm.
- As suggested in [3], well-orgaized TAL management framework to find the optimal distributions of TAs in the form of TAL.
- TA reconfiguration using game theory reduces the overall signalling cost of the network.
- Unifying the TA of 4G and 5G layers to minimize the unnecessary TAUs.
- Clustering algorithms is used for reducing the paging cost. 3GPP proposals for 5G architectures and their hybrid are compared with respect to overall signalling overhead and energy of UEs.

Chapter 2

Literature Review

There are various methods proposed in literature to optimize the cost incurred towards TAU [16-20]. The methods can be categorized into static and dynamic schemes. In static location update methods, the TAs are fixed, and UEs perform area update when there is a change in their locations [21]. In dynamic schemes, TAUs are based on the variation in the mobility pattern of UEs with respect to time. Dynamic area update schemes are comparatively complex, and estimation cost is more as compared to static schemes as the former requires data and mobility profile of the user. Examples of these schemes are Always Update, Never Update, Reporting Cells, and Forming Location Areas [22-24].

The other factor that affects the overall signalling cost of the network is paging cost. Generally, paging is needed to find the exact location of the user at cell level [25]. Steps taken to track the user's position by sending signals through the downlink channel form the polling cycle. During this cycle, only the user who is called, respond to the signal through uplink control channel. Reducing signalling overhead is a big challenge for the network operators.

2.1 Drawbacks of Conventional Tracking Area

In conventional TA design, cells (sites) form mutually disjoint sets. Generally, a site does not belong to more than one TA in the standard scheme. It has some limitations in the form of causing overloading in network in specific scenarios:

Ping-Pong Effect

This situation arises when UEs are having mobility at the border of adjacent TAs, as shown in Fig. 2.1. The UEs move between two TAs causing excessive TAU, and hence termed as ping-pong-TAU effect.

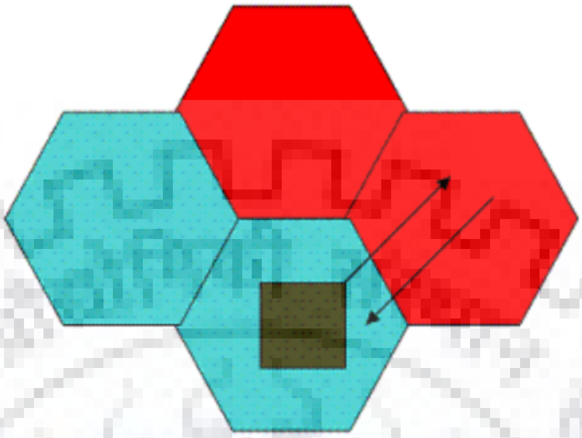


Fig. 2.1. Ping-pong effect [2]

Symmetry Limitation

In conventional design, TA symmetry issue always exists. Suppose there are two sites named X and Y. If site X considers site Y in the same TA, then for site Y also site X will be in the same TA. Therefore, there is a need to design a more flexible network so as to reduce this limitation.

Massive Mobility Signalling Congestion

Fig. 2.2 shows a train scenario in which a very large number of UEs are travelling and entering into a new TA. There is a likelihood of uncontrolled TAUs from the UEs in a very small spell of time. The quality of service gets compromised in this scenario.

2.2 Tracking Area List

TAL scheme is adopted to give more flexibility while designing TA. It is supposed to overcome the limitations of conventional TA design [3]. It has been proposed in literature that TAL will reduce the frequency of TAU by assigning TAs to TAL depending on the mobility pattern of UEs. In order to reduce the cost incurred towards TAU due to ping

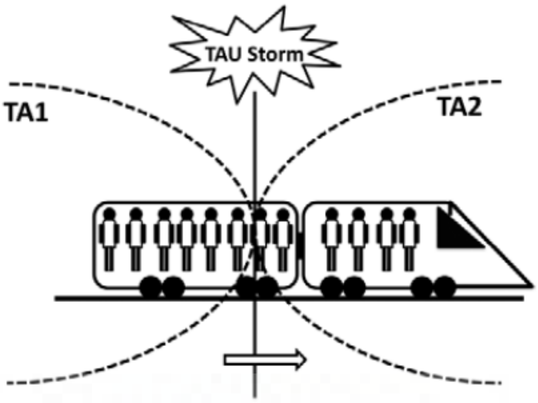


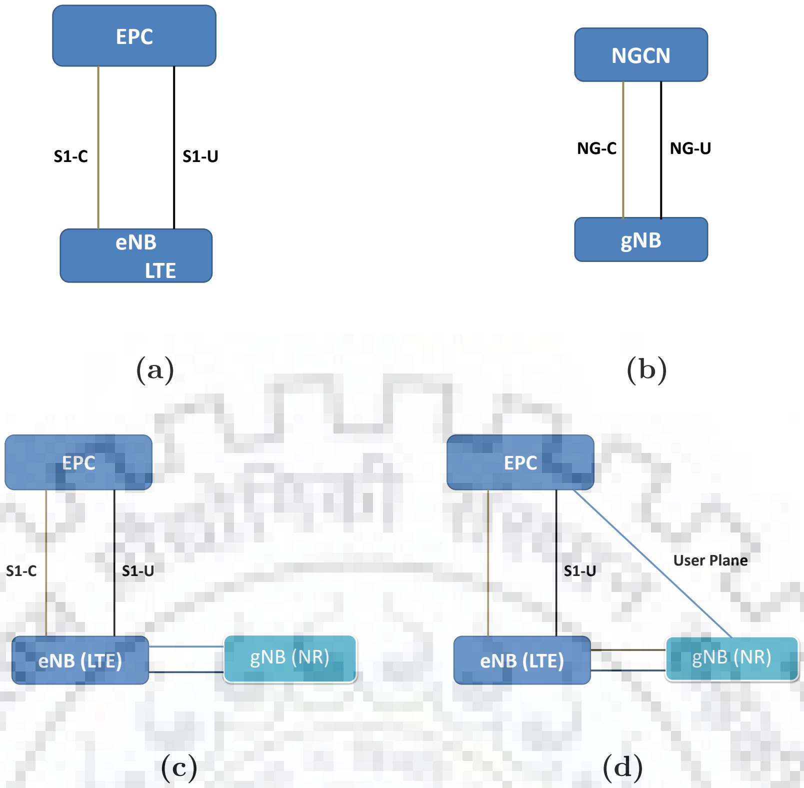
Fig. 2.2. Train scenario [2]

pong effect in 4G and upcoming 5G networks, it has been proposed that TAL will contain the last visited TA.

2.3 Next Generation Possibilities for Deployment

Fig. 2.3(a) shows Stand alone (SA) LTE, evolved packet core (EPC) legacy architecture. This is the classic architecture of the 4G networks in use today [1]. The eNodeB has basically the remote radio head, the antennas, the baseband unit and a small router to interconnect other eNodeBs. It is also connected into the EPC with the control plane (CP) and the user plane (UP). But moving to the new radio (NR) and the front-end architecture of the eNodeB is going to evolve yet again. The gNodeB for the next generation node B, shown in Fig. 2.3(b), is going to support the new radio. NR is going to operate at much higher frequencies than the traditional eNodeB's and operating for the last few years instead of topping out at ground perhaps 5 or 6 GHz are going to be entering the realm of frequencies as high as 28, 29 or 30 GHz or in the future even higher [10]. In particular configuration as shown in Fig. 2.3(c), the gNodeB is going to have it's UP and CP connected to the EPC via the eNodeB. This is known as 3GPP non-standalone (NSA) LTE assisted configuration. Fig. 2.3(d) shows another option, where the gNodeB is connected directly to the EPC but with the user playing only the CP still have to go via the eNodeB. This allows to leverage existing 4G deployments by creating 5G hotspots with the NR technology relatively quickly and the new 5G services which are going to require the higher speeds associated with the new radio and the high performance.

Fig. 2.4(a) shows SA which is only for greenfield operators. Therefore, if an operator that does not really have a legacy network the gNodeB can be deployed and intercon-

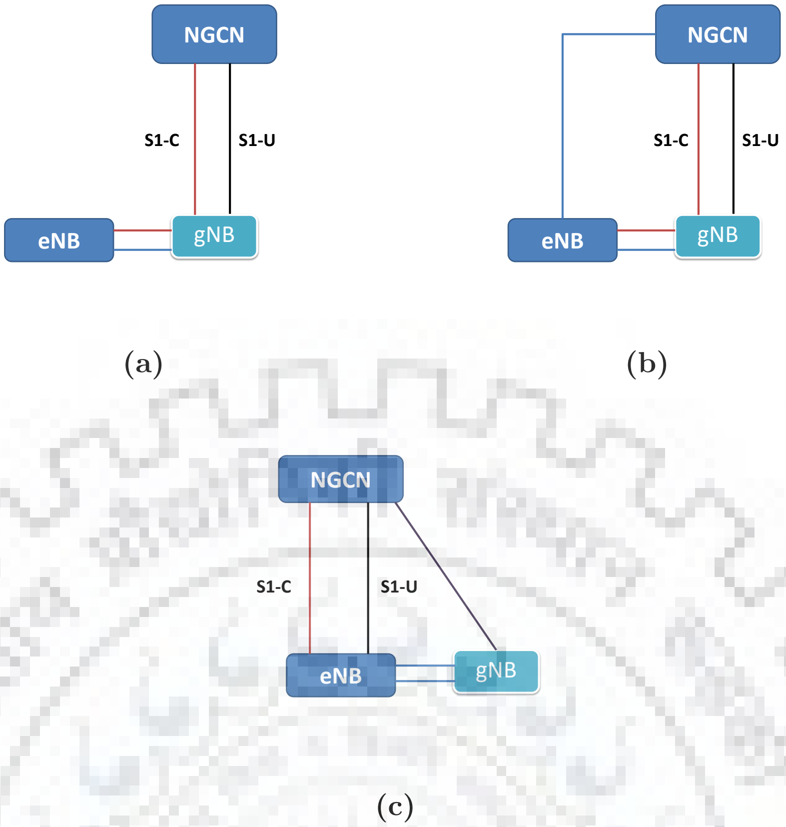


(a) (b) (c) (d)

Fig. 2.3. Initial architectures (a) SA-LTE legacy architecture; (b) 3GPP-15 SA architecture; (c) NSA-LTE assisted architecture; (d) 3GPP-15 NSA architecture [1,3]

nected to the next generation core network (NGCN) with the CP and the UP. NGCN is substantially different from the typical EPC that are being used today. It's not always going to be necessary to scale the performance of both UP and CP at the same level as it really depends on the applications. For example, machine to machine communication (mMTC) applications require the CP to be scaled more extensively. Therefore, for these green field operators will be able to fully support the new 5G services with eMBB offering very high speeds, mMTC up to a million devices per square km, URLLC round trip rounds to the gNodeB in the millisecond range but to give complete coverage the gNodeB will have to support a wide spectrum for short range high capacity throughput as well as long reach so different spectrums for different applications.

As shown in Fig. 2.4(b), the architecture shows another possible option by removing the EPC and connect the new gNodeB directly to the new NGCN again using the CP and UP. This allows to replace the EPC with the NGCN. This is for the operators driven by the capacity not just by the coverage and this allows to use the new 5G services quite quickly. Fig. 2.4(c) shows another option by simply changing the core in which the core network is available when the new NGCN is available. It may be more advantageous to



(a) (b) (c)

Fig. 2.4. Evolution architectures (a) NSA-LTE assisted; (b) NSA-NR assisted (gNB as a CP); (c) NSA-NR assisted (eNB as a CP) [1,3]

simply swap out the EPC for the NGCN in which, eNodeB will maintain its connection directly to the NGCN and it, in turn, will be connected to the gNodeB. The gNodeB will be supporting the NR and the higher performance associated with it but for good coverage, still need a lot of the technology running there in the eNodeB. The advantage here with just changing the core only is that the network interfaces routing tables etc remain unchanged so this reduces the impact on upgrading the new gNodeB and the NR. Therefore, gNodeB is added via the eNodeB.

A wide spectrum is supported for different requirements and different applications. The sub 1GHz range (from 600 MHz to 1 GHz range) will be used for the M2M communications and IoTs types of applications [1, 5]. For large capacity vehicle to vehicle (V2V) communications V2X type communications, where very low latency is required, spectrum from 1 GHz to 6 GHz will be used. In the higher frequencies and the 6GHz to possibly even 100 GHz augmented reality (AR) and virtual reality (VR) applications with much better resolution and good quality of experience (QoE) will be supported.

Chapter 3

Tracking Area Problem

3.1 Problem Formulation

Assume that $\hat{C} = [1, 2, ..., C]$ means the arrangement of cells (sites), and $\hat{L} = [1, 2, ..., L]$ indicates the arrangement of TAs that are being used. The vector $\mathbf{v} = [v_1, v_2, ..., v_C]$ is used for cell-to-TA allotment, where v_a denotes the TA of cell a. The TA plan $\mathbf{v}$ can be denoted by a $C \times C$ symmetric and a binary matrix $X(\mathbf{v})$. The component $x_{ab}(\mathbf{v})$ is one if $v_a = v_b$, implying that the two cells are having same TA else it will be 0.

$$x_{ab}(\mathbf{v}) = \begin{cases} 1\ ; & \text{if}\ \ v_a = v_b \\ 0\ ; & \text{otherwise} \end{cases} \tag{3.1}$$

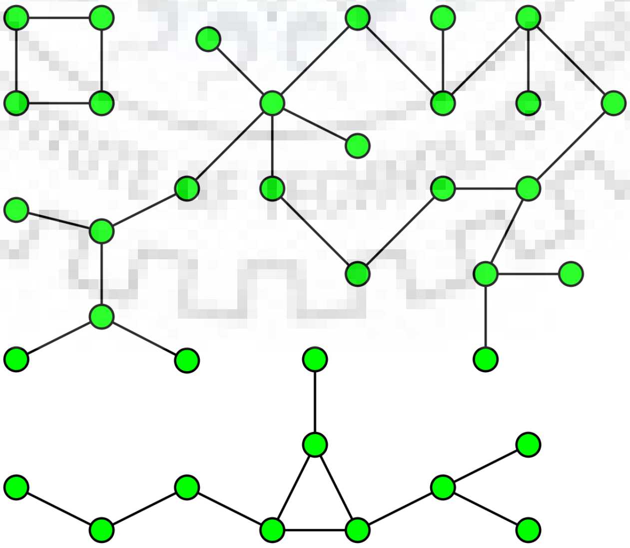


Fig. 3.1. NBs (cells) forming clusters [2]

The overall signalling overhead $O_{so}(l)$ of a network can be represented as a sum of

TAU overhead and paging overhead, *i.e.*

$$O_{so}(\mathbf{v}) = \sum_{a\in\hat{C}} \sum_{b\in\hat{C}:b\neq a} O^u y_{ab}(1 - x_{ab}(\mathbf{v}) + \alpha O^p e_a x_{ab}(\mathbf{v}) \tag{3.2}$$

where e_a represents the overall users in site (cell) a, y_{ab} denotes the number of UEs that are moving from site a to b for the same duration, O^u denotes the single TAU overhead, O^p represents single paging overhead, and α denotes the probability that a UE is paged.

Assume $\mathbf{v^0}$ is reconfigured to $\mathbf{v}$. All sites for which the appointed TAs differ in $\mathbf{v^0}$ and $\mathbf{v}$ are influenced by reconfiguration. Let $r(\mathbf{v})$ denotes the reconfiguration cost of the system, given by

$$r(\mathbf{v}) = \sum_{a\in\hat{C}} e_i d_i(\mathbf{v}, \mathbf{v^0}) \tag{3.3}$$

Let $d(\mathbf{v}, \mathbf{v^0})$ defines a binary vector characterizing sites which have been alloted new TAs. $d_i(\mathbf{v}, \mathbf{v^0})$ for $i \in \hat{C}$ is characterized as

$$d_i(\mathbf{v}, \mathbf{v^0}) = \begin{cases} 1\ ; & \text{if } \ v_i^0 \neq v_i \\ 0\ ; & \text{otherwise} \end{cases} \tag{3.4}$$

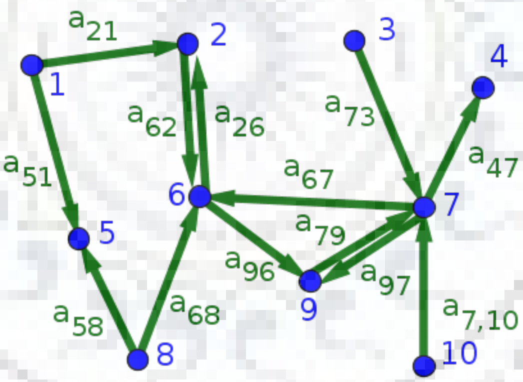


Fig. 3.2. Mobility of users [2]

Fig. 3.1 shows the cluster formation by different nodes to reduce the signalling cost of the network. However, it will lead to the increased reconfiguration cost of the network. In Fig. 3.2, a_{ij} for $i \neq j$, points to the movement of users from j^{th} NB to i^{th} NB. Table 3.1 shows the node (cell) data, TAU overhead and paging overhead for the movement of UEs. This data set is self generated depending on the density of UEs for a given node (cell).

In contrast to the conventional techniques which may not ensure a fair trade-off between the conflicting objectives, a Nash bargaining technique is used in the proposed work to get the optimal signalling cost.

Table 3.1: Data for movement and paging weights

Node	O^u	O^p	Node	O^u	O^p
1	1400	160	19	1010	109
2	1480	164	20	1271	127
3	945	134	21	1671	181
4	1545	174	22	941	105
5	1545	174	23	1000	115
6	1545	174	24	1051	154
7	1045	144	25	1331	164
8	1045	144	26	951	105
9	945	134	27	951	105
10	945	134	28	961	110
11	945	134	29	871	105
12	1245	144	30	871	105
13	1245	144	31	871	105
14	1245	144	32	961	110
15	1245	144	33	1065	130
16	1245	144	34	1056	127
17	1045	144	35	1056	127
18	1088	150	36	1056	127

3.2 Simulation Results

Fig. 3.3 shows the model for mobility of UEs. Dots marked in Fig. 3.3 are UEs, moving freely in different directions with different speeds. The list of TAs assigned to UEs and cluster formation of nodes will be dependent on UE's mobility pattern. Frequently visited nodes by UEs need to be a part of the same TA, to reduce the TAU cost. Considering the second scenario in which UEs are not that mobile, more UEs are idle in a given TA. Therefore, paging cost will be more as nodes form a large cluster. The proposed technique based on game theory finds the solution that provides a fair trade-off between these two conflicting objectives (TAU overhead and paging cost).

The simulation study is carried out in Matlab environment. The movement of UEs for the simulation purpose is governed in a manner that each dot (UE) moves to a new position depending on the speed which is randomly chosen between 0 (excluded) and some maximum speed.

Fig. 3.4 shows that as the user moves from one node to the other, there is a variation in signal-to-noise ratio (SNR). As the user reaches a new position, there will be new node

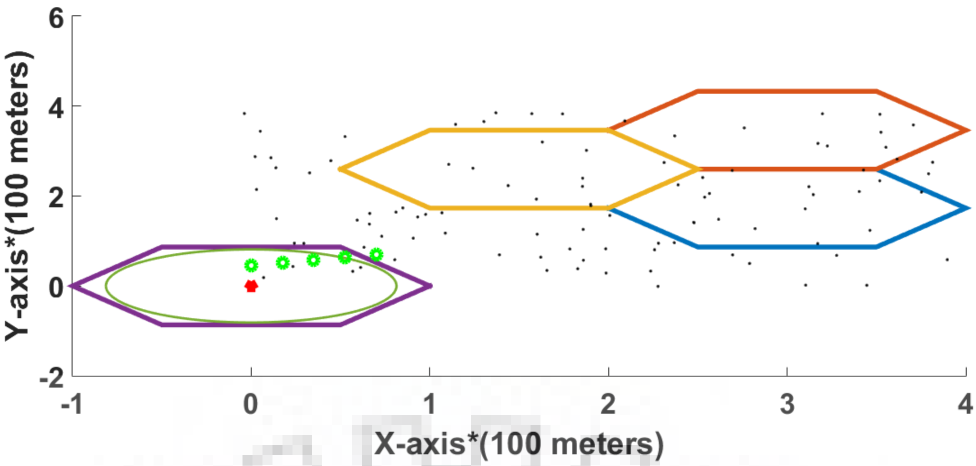


Fig. 3.3. UE's random walk between cells

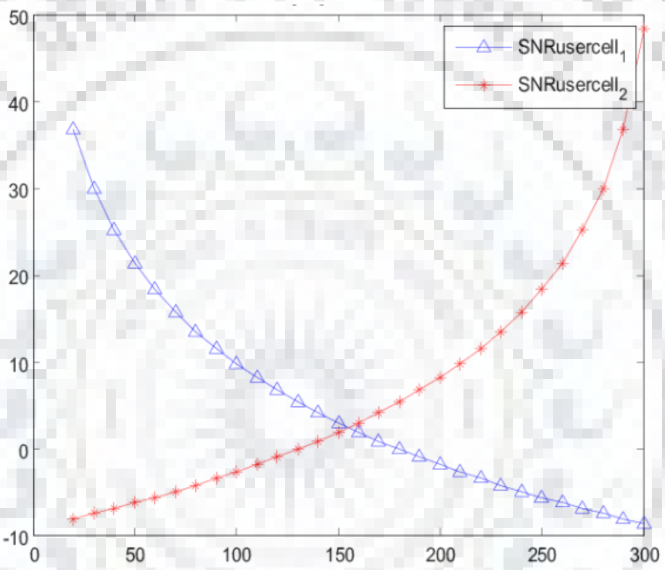


Fig. 3.4. SNR (in dB) vs distance (in meter)

(cell) supporting the UE. As a result, there will be TAU for the UE. If the number of cells and number of UEs are increased, there will be huge signalling cost limiting the network performance. Therefore, the task is to assign nodes to TAs to reduce signalling overhead, and make the network more flexible.

In the simulation study, the cells are deployed over the network randomly. The network is initialized with random group of cells. Fig. 3.5 shows that as the reconfiguration cost increases, there is a reduction in the overall signalling overhead of the deployed network. When the reconfiguration cost increases, depending on the mobility pattern of UEs, nodes start forming cluster (TA), shown in Fig. 3.1, to minimize the overall signalling overhead of the network. Fig. 3.5 shows the comparison between results achieved using the proposed game theory based technique with those obtained from the genetic algorithm (GA) based solution to the location area planning. The simulation study con-

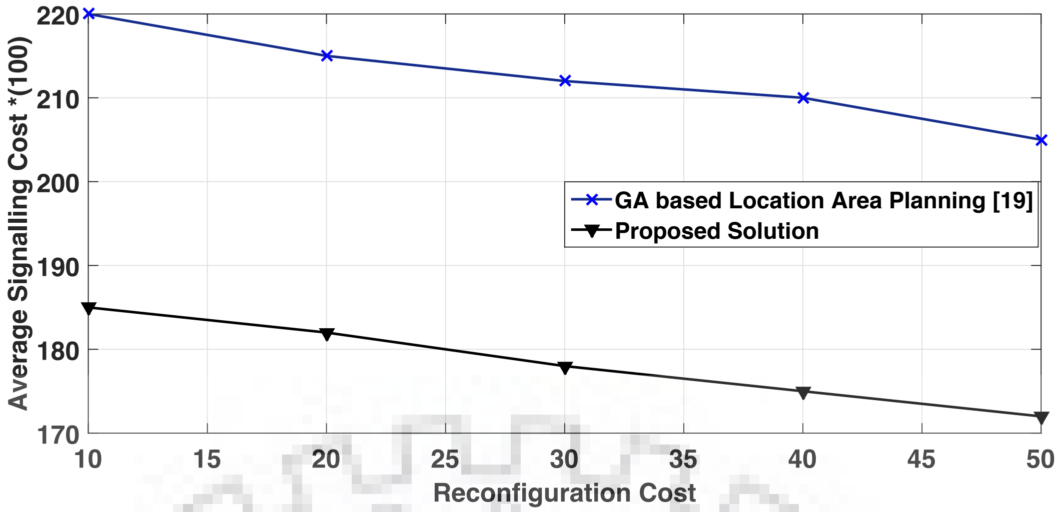


Fig. 3.5. Signalling cost when 5 TAs are used

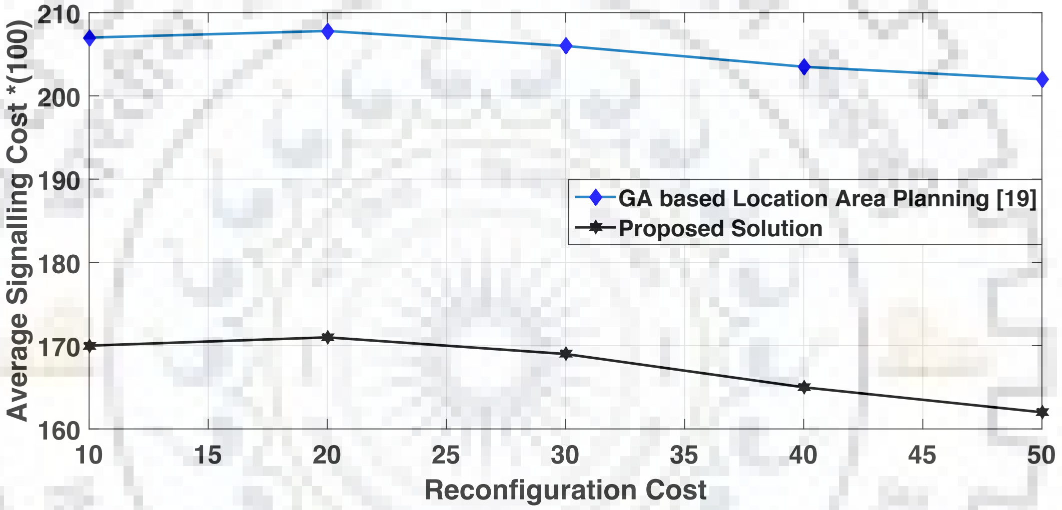


Fig. 3.6. Signalling cost when 3 TAs are used

siders 36 nodes and 5 TAs. Depending on the UE's mobility, nodes will form cluster (TAs), and the network will adapt to the mobility pattern of UE and reconfigure itself. Considering the second scenario of 3 TAs in Fig. 3.6, the cost incurred towards TAU is low as compared to the first scenario of 5 TAs in Fig. 3.5. However, the paging cost is more as the number of idle UEs within the TAs will be more in the second scenario. When the reconfiguration cost increases in the second scenario, the signalling overhead initially increases marginally because of smaller number of clusters compared to the first scenario, causing more paging cost. Thereafter, as the reconfiguration cost increases, nodes form cluster in such a way so that the overall signalling overhead of the network can be minimized. As the reconfiguration cost increases, there will be reduction in the overall cost of the network.

Chapter 4

Exploiting Tracking Area List

4.1 Network Framework

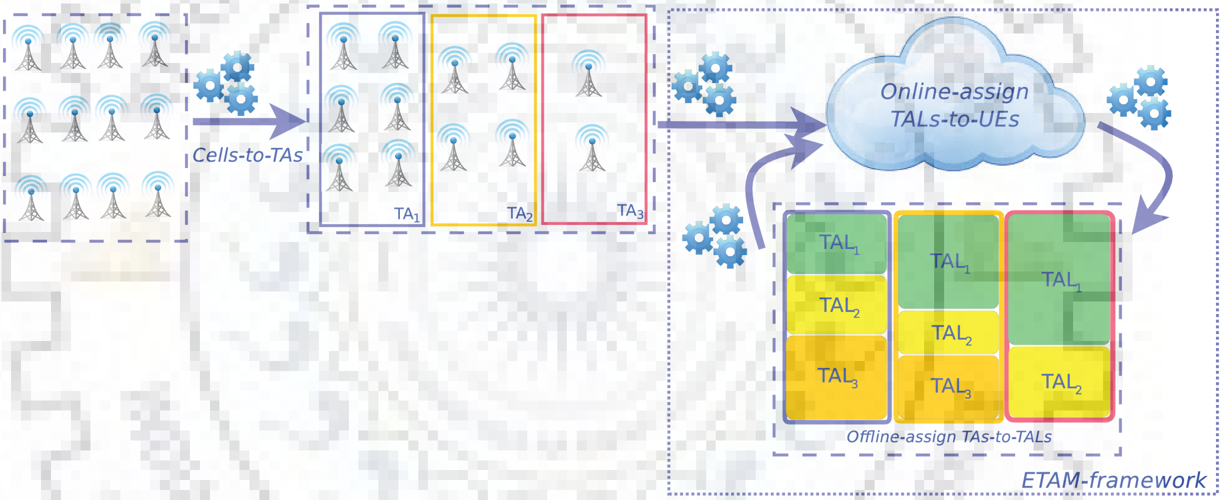


Fig. 4.1. Network framework [3]

As suggested in [3], Fig. 4.1 shows the summary of the TA supervision for the 5G networks. The network is partitioned into different sites. These sites are controlled by nodeBs (NBs) and the geographically closed NBs form a group termed as TA. The previous chapters have already discussed about the limitation of the conventional TA design. Therefore, to overcome the limitations of the convectional TA design 3GPP release 12 proposed the concept of TAL design. In TAL design the UE is having the list of TAs (maximum up to 15) and this list will be allotted to the UEs depending on their mobility behavior when it enters in the new TA that is not the part of the list. When the UEs leave its TA and enters into a new TA that is not contained in the list, then new list of TAs will be allotted to the UEs. To avoid the ping-pong effect the list contains the last visited TA. As shown in Fig. 4.1, each TA is considered as a distinct TAL. After initializing, the second step is to meet the best possible solution by the allotment of TAs to list and then lists are allotted to the UE depending on the mobility behavior of UE, executed offline and online respectively.

4.2 Allotment of TAs to TALs

Towards the finish of this progression, a matrix S is created, whereby the TAs are represented in rows and TALs in columns respectively. A component S_{mn} alludes to the likelihood that TA m allots list n to various users. The sites having a place with the equivalent TA m utilize a similar row m in the matrix S to allot lists to various UEs. The consequence of this progression is utilized by the online advance of the system structure to allot distinctive TALs to various UEs. The first optimization solution is by favouring TAU cost is a Linear program (LP) and second one is also a LP by favouring paging cost. The last one is a convex optimization problem which goes for the trade-off between TAU and paging costs.

4.2.1 Optimizing by Favouring TAU Cost

In this part F-TAU solution is proposed by the author which favours TAU overhaed and min-max methodology is used to obtain the finest allotments of TALs. The model can be devised according to the linear program (4.1)-(4.6):

$$\mathbf{min} \max_{\forall m,n \in \hat{\mathcal{L}} \wedge m \neq n} O^{TAU} \left(\sum_{t_l \in \Gamma_m \wedge t_l \notin \Gamma_n} y_{mn} S_{mt_l} + \sum_{t_l \in \Gamma_n \wedge t_l \notin \Gamma_m} y_{nm} S_{nt_l} \right) \tag{4.1}$$

$s.t,$

$$\forall t_l \in \Gamma, \forall m \in \hat{\mathcal{L}} \cap t_l, \mathcal{S}_{mt_l} \geq 0 \tag{4.2}$$

$$\forall t_l \in \Gamma, \forall m \in \hat{\mathcal{L}} \cap t_l, \mathcal{S}_{mt_l} \leq 1 \tag{4.3}$$

$$\forall m \in \hat{\mathcal{L}}, \sum_{t_l \in \Gamma} \mathcal{S}_{mt_l} = 1 \tag{4.4}$$

$$\forall t_l \in \Gamma, \forall m \notin \hat{\mathcal{L}} \cap t_l, \mathcal{S}_{mt_l} = 0 \tag{4.5}$$

$$O^{paging} \sum_{t_l \in \Gamma} \sum_{m \in t_l} \mathcal{S}_{mt_l} \left(\sum_{k \in \hat{U}} \beta_k \mathcal{N}_{km} \right) \left(\sum_{n \in t_l \wedge n \neq m} \hat{c}_n \right) \leq PAGING_{max} \tag{4.6}$$

Equations (4.2)-(4.4) are making sure that each TA $m \in \hat{L}$ allots its TAL with certain probability from S_m . The constraint in (4.5) is to ensure that a TA consigns TALs to UEs only if it is contained in TALs. The constraint in (4.6) is to ensure that the overall paging cost of the network should not go beyond a predefined upper limit $PAGING_{max}$ ($PAGING_{max}$ can be set to ∞). For any TAL t, the overhead brought about by paging UEs dwelling in TA $m \in t_l$ is the number of cells $\hat{c}_n$ in these TAs, scaled by $\sum_{k \in \hat{U}} \beta_k \mathcal{N}_{km}$ and a variable S_{mt_l}. $\sum_{k \in \hat{U}} \beta_k \mathcal{N}_{km}$ is a consistent that speaks to the paging overhead at TA m.

4.2.2 Optimizing by Favouring Paging Cost

In this part F-PAGING solution is proposed by the author which favors paging overhaed and min-max methodology is used to obtain the finest allotments of TALs. The objective is to minimize paging cost of the network. The model can be devised according to the LP given in (4.7)-(4.12):

$$\textbf{min } O^{paging} \sum_{t_l \in \Gamma} \sum_{m \in t_l} \left(\mathcal{S}_{mt_l} \left(\sum_{k \in \hat{U}} \beta_k \mathcal{N}_{km} \right) \sum_{n \in t_l \wedge n \neq m} \hat{c}_j \right) \tag{4.7}$$

$s.t,$

$$\forall t_l \in \Gamma, \forall m \in \hat{\mathcal{L}} \cap t_l, \mathcal{S}_{mt_l} \geq 0 \tag{4.8}$$

$$\forall t_l \in \Gamma, \forall m \in \hat{\mathcal{L}} \cap t_l, \mathcal{S}_{mt_l} \leq 1 \tag{4.9}$$

$$\forall m \in \hat{\mathcal{L}}, \sum_{t_l \in \Gamma} \mathcal{S}_{mt_l} = 1 \tag{4.10}$$

$$\forall t_l \in \Gamma, \forall m \notin \hat{\mathcal{L}} \cap t_l, \mathcal{S}_{mt_l} = 0 \tag{4.11}$$

$\forall m, n \in \hat{\mathcal{L}} \wedge m \neq n :$

$$O^{TAU} \left(\sum_{t_l \in \Gamma_m \wedge t_l \notin \Gamma_n} y_{mn} S_{mt_l} + \sum_{t_l \in \Gamma_n \wedge t_l \notin \Gamma_m} y_{nm} S_{nt_l} \right) \leq TAU_{max} \tag{4.12}$$

The constraints in (4.8)-(4.11) are same as the LP (4.2)-(4.5) mentioned in the above section. The constraint in (4.12) is to ensure that the overall TAU cost of the network should not go beyond a predefined upper limit TAU_{max} (TAU_{max} can be set to ∞).

4.2.3 Trading off TAU against Paging

As opposed to the regular systems used to tackle the multi-objective problems, which may not guarantee a reasonable trade-off between the contradictory objectives, fair and optimal TA assignment (FOTA) utilizes a Nash dealing amusement to accomplish this trade-off.

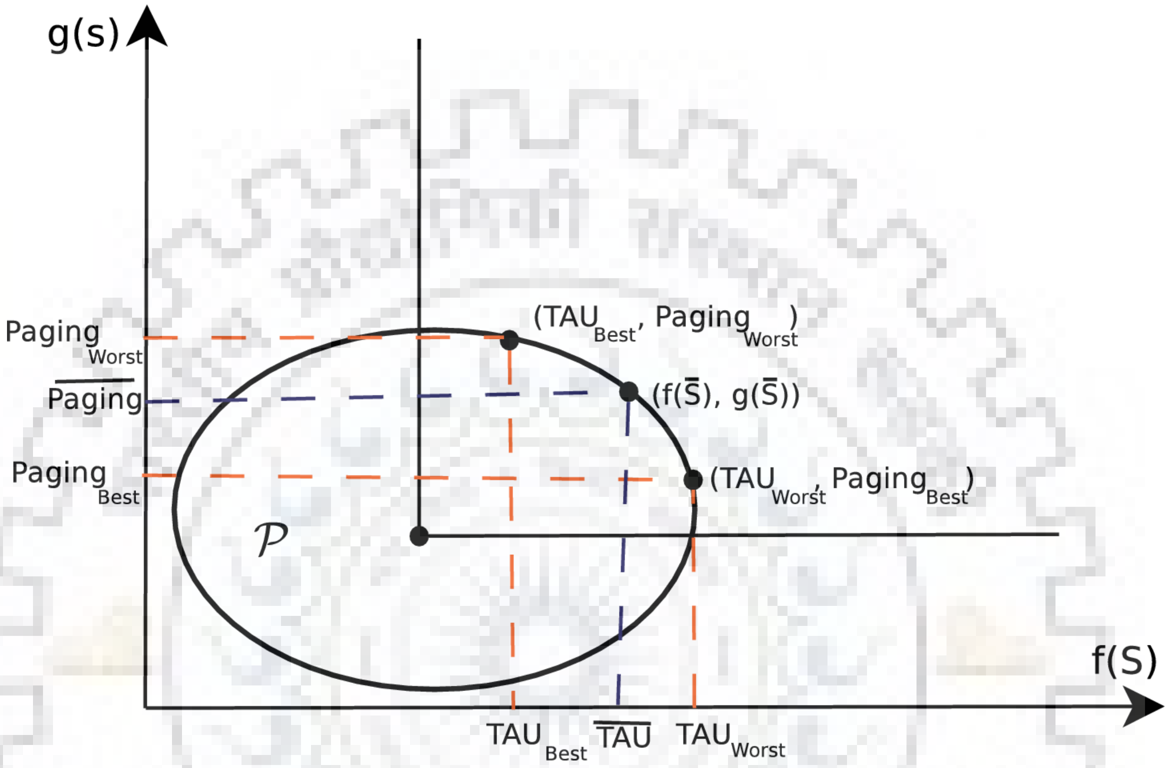


Fig. 4.2. Geometric interpretation of trade-off [3]

It was hypothetically demonstrated in [17] that the utilization of Nash bartering diversion guarantees a reasonable trade-off between the players as per the system attributes as far as UE's mobility and call proportion. FOTA will support the decrease of TAU cost for a system described by a high user movement, while it will support the decrease of paging cost for a system with a high call proportion. Geometric interpretation of trade-off is shown in Fig. 4.2.

The trade-off between TAU and paging costs is given by (4.13)-(4.21).

$$\mathbf{max}\ (TAU_{worst} - f(\mathcal{S}))(PAGING_{worst} - g(\mathcal{S})) \tag{4.13}$$

$s.t,$

$$\forall t_l \in \Gamma, \forall m \in \hat{\mathcal{L}} \cap t_l, \mathcal{S}_{mt_l} \geq 0 \tag{4.14}$$

$$\forall t_l \in \Gamma, \forall m \in \hat{\mathcal{L}} \cap t_l, \mathcal{S}_{mt_l} \leq 1 \tag{4.15}$$

$$\forall m \in \hat{\mathcal{L}}, \sum_{t_l \in \Gamma} \mathcal{S}_{mt_l} = 1 \tag{4.16}$$

$$\forall t_l \in \Gamma, \forall m \notin \hat{\mathcal{L}} \cap t_l, \mathcal{S}_{mt_l} = 0 \tag{4.17}$$

$$\forall m, n \in \hat{\mathcal{L}} \wedge m \neq n :$$

$$O^{TAU} \left(\sum_{t_l \in \Gamma_m \wedge t_l \notin \Gamma_n} y_{mn} S_{mt_l} + \sum_{t_l \in \Gamma_n \wedge t_l \notin \Gamma_m} y_{nm} S_{nt_l} \right) \leq f(\mathcal{S}) \tag{4.18}$$

$$O^{paging} \sum_{t_l \in \Gamma} \sum_{m \in t_l} \mathcal{S}_{mt_l} \left(\sum_{k \in \hat{U}} \beta_k \mathcal{N}_{km} \right) \left(\sum_{n \in t_l \wedge n \neq m} \hat{c}_n \right) \leq g(\mathcal{S}) \tag{4.19}$$

$$f(\mathcal{S}) \leq TAU_{worst} \tag{4.20}$$

$$g(\mathcal{S}) \leq PAGING_{worst} \tag{4.21}$$

The estimations of $PAGING_{best}, PAGING_{worst}, TAU_{best}$ and TAU_{worst} are acquired by refreshing the LPs (4.1)-(4.6) as:

$$\textbf{min } f(\mathcal{S}) \tag{4.22}$$

$s.t,$

$$\forall t_l \in \Gamma, \forall m \in \hat{\mathcal{L}} \cap t_l, \mathcal{S}_{mt_l} \geq 0 \tag{4.23}$$

$$\forall t_l \in \Gamma, \forall m \in \hat{\mathcal{L}} \cap t_l, \mathcal{S}_{mt_l} \leq 1 \tag{4.24}$$

$$\forall m \in \hat{\mathcal{L}}, \sum_{t_l \in \Gamma} \mathcal{S}_{mt_l} = 1 \tag{4.25}$$

$$\forall t_l \in \Gamma, \forall m \notin \hat{\mathcal{L}} \cap t_l, \mathcal{S}_{mt_l} = 0 \tag{4.26}$$

$\forall m, n \in \hat{\mathcal{L}} \wedge m \neq n :$

$$O^{TAU} \left(\sum_{t_l \in \Gamma_m \wedge t_l \notin \Gamma_n} y_{mn} S_{mt_l} + \sum_{t_l \in \Gamma_n \wedge t_l \notin \Gamma_m} y_{nm} S_{nt_l} \right) \leq TAU_{best} \tag{4.27}$$

$$O^{paging} \sum_{t_l \in \Gamma} \sum_{m \in t_l} \mathcal{S}_{mt_l} \left(\sum_{k \in \hat{U}} \beta_k \mathcal{N}_{km} \right) \left(\sum_{n \in t_l \wedge n \neq m} \hat{c}_j \right) \leq PAGING_{worst} \tag{4.28}$$

$$PAGING_{worst} \leq PAGING_{max} \tag{4.29}$$

$$TAU_{best} \leq f(\mathcal{S}) \tag{4.30}$$

Also, LPs (4.7)-(4.12) can be refreshed as:

$$\mathbf{min}\ g(\mathcal{S}) \tag{4.31}$$

$$s.t,$$

$$\forall t_l \in \Gamma, \forall m \in \hat{\mathcal{L}} \cap t_l, \mathcal{S}_{mt_l} \geq 0 \tag{4.32}$$

$$\forall t_l \in \Gamma, \forall m \in \hat{\mathcal{L}} \cap t_l, \mathcal{S}_{mt_l} \leq 1 \tag{4.33}$$

$$\forall m \in \hat{\mathcal{L}}, \sum_{t_l \in \Gamma} \mathcal{S}_{mt_l} = 1 \tag{4.34}$$

$$\forall t_l \in \Gamma, \forall m \notin \hat{\mathcal{L}} \cap t_l, \mathcal{S}_{mt_l} = 0 \tag{4.35}$$

$$\forall m, n \in \hat{\mathcal{L}} \wedge m \neq n :$$

$$O^{TAU} \left(\sum_{t_l \in \Gamma_m \wedge t_l \notin \Gamma_n} y_{mn} S_{mt_l} + \sum_{t_l \in \Gamma_n \wedge t_l \notin \Gamma_m} y_{nm} S_{nt_l} \right) \leq TAU_{worst} \tag{4.36}$$

$$O^{paging} \sum_{t_l \in \Gamma} \sum_{m \in t_l} \mathcal{S}_{mt_l} \left(\sum_{k \in \hat{U}} \alpha_k \mathcal{N}_{km} \right) \left(\sum_{n \in t_l \wedge n \neq m} \hat{c}_j \right) \leq PAGING_{best} \tag{4.37}$$

$$PAGING_{best} \leq g(\mathcal{S}) \tag{4.38}$$

$$TAU_{worst} \leq TAU_{max} \tag{4.39}$$

The optimization problem appeared in the LP (4.13-(4.21) is non-convex but it can be changed to a convex problem without changing the arrangement. The improvement is reformulated as:

$$\mathbf{max}\,\log((TAU_{worst} - f(\mathcal{S}))) + \log((PAGING_{worst} - g(\mathcal{S}))) \tag{4.40}$$

$$s.t,$$

$$\forall m, n \in \hat{\mathcal{L}} \wedge m \neq n :$$

$$O^{TAU} \left(\sum_{t_l \in \Gamma_m \wedge t_l \notin \Gamma_n} y_{mn} S_{mt_l} + \sum_{t_l \in \Gamma_n \wedge t_l \notin \Gamma_m} y_{nm} S_{nt_l} \right) \leq f(\mathcal{S}) \tag{4.41}$$

$$O^{paging} \sum_{t_l \in \Gamma} \sum_{m \in t_l} \mathcal{S}_{mt_l} \left(\sum_{k \in \hat{U}} \beta_k \mathcal{N}_{km} \right) \left(\sum_{n \in t_l \wedge n \neq m} \hat{c}_j \right) \leq g(\mathcal{S}) \tag{4.42}$$

$$f(\mathcal{S})) \leq TAU_{worst} \tag{4.43}$$

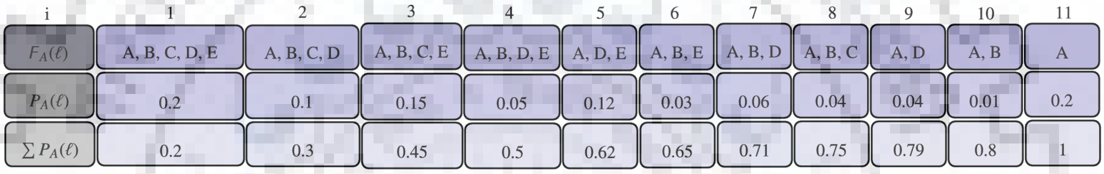
$$g(\mathcal{S})) \leq PAGING_{worst} \tag{4.44}$$

4.3 Allotment of TALs

The possibility to allot TAL ℓ in TA i to the users in matrix S is represented by an element $S_{i\ell}$, where TAs are represented in different rows and TALs are through columns. Matrix S is produced in offline step such that the TAL that gives best possible result for the given network is more probable to be allotted to the users. Γ_i, for $\forall i \in \hat{N}$, can be described as:

$$\Gamma_i = \{\ell, S_{i,\ell} \neq 0 \;\; for\ \forall \ell \in \Gamma \wedge i \in \ell\} \tag{4.45}$$

When a user enters a $TA\ i$, MME will allot to this user a TAL from Γ_i . The elements Γ_i are arranged on the basis of decreasing probabilty and denoted by $\mathcal{F}_i$. $P_i(\ell)$, the likelihood to allot list by TA, can be deduced from the matrix S. Fig. 4.3 illustrates an example of $\mathcal{F}_i$ and P_A.



i	1	2	3	4	5	6	7	8	9	10	11
$\mathcal{F}_A(\ell)$	A, B, C, D, E	A, B, C, D	A, B, C, E	A, B, D, E	A, D, E	A, B, E	A, B, D	A, B, C	A, D	A, B	A
$P_A(\ell)$	0.2	0.1	0.15	0.05	0.12	0.03	0.06	0.04	0.04	0.01	0.2
$\sum P_A(\ell)$	0.2	0.3	0.45	0.5	0.62	0.65	0.71	0.75	0.79	0.8	1

Fig. 4.3. Allotment of TALs: An example [3]

4.3.1 Allotting Lists to Users without Prioritization

In this case, the likelihood of each TAL denoted as $P_A(\ell)$ is utilized, for example, no prioritization among users is considered. All UEs have a similar need to acquire any TAL from the visited TAs. This methodology could be utilized to lessen the contribution of UEs (and henceforth related overhead and battery utilization) in the TAL assignment process. For this situation, when a UE u visits another TA A, the MME creates variable $V_1 \in [0, 1]$ utilizing a uniform distribution. At that point, TAL ℓ is allotted to UE u as the one that fulfills the accompanying condition:

$$\sum_{k=1}^{\ell-1} P_A(k) < \mathbf{V}_1 \leq \sum_{k=1}^{\ell} P_A(k) \tag{4.46}$$

Utilizing the model as shown in Fig. 4.3, on the off chance that $V_1 = 0.38$, at that point TAL 3 would be alloted to UE u.

4.3.2 Allotting Lists to Users with Prioritization

In this procedure, UEs showing higher movement than paging, ought to get TALs having enormous number of TAs to alleviate the impact of TAU cost. In this case TAL with maximum number of TAs will be allotted to UE, shown in Fig. 4.4, so as to lessen the TAU cost. In case the UE is not mobile and paging cost is more then TAL with one or small number of TAs will be allotted.

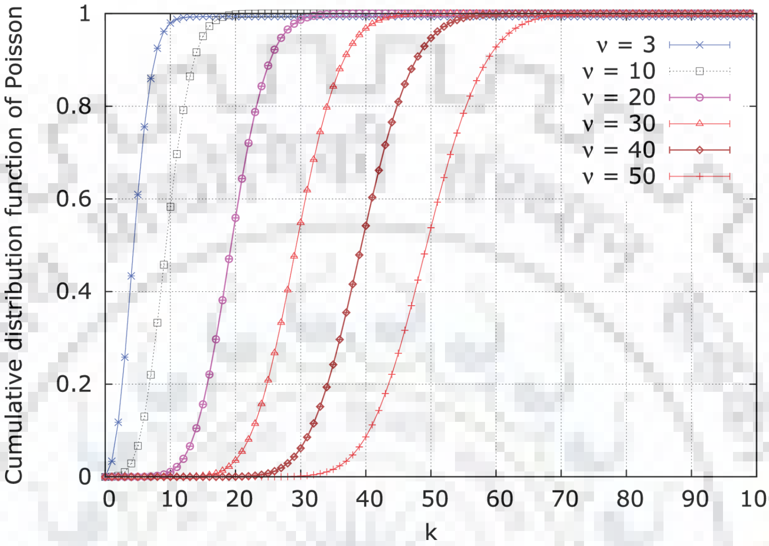
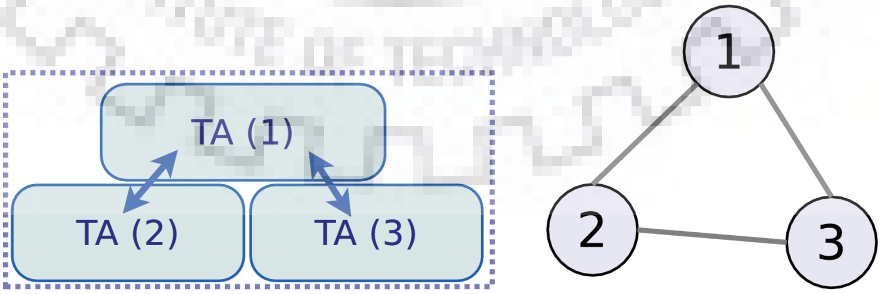


Fig. 4.4. CDF of Poisson distribution

4.4 Analytical Model

In this section, a Markov-based model is used for analysing all the offline solution by considering the network as shown in Fig. 4.5 to ease the explaination.

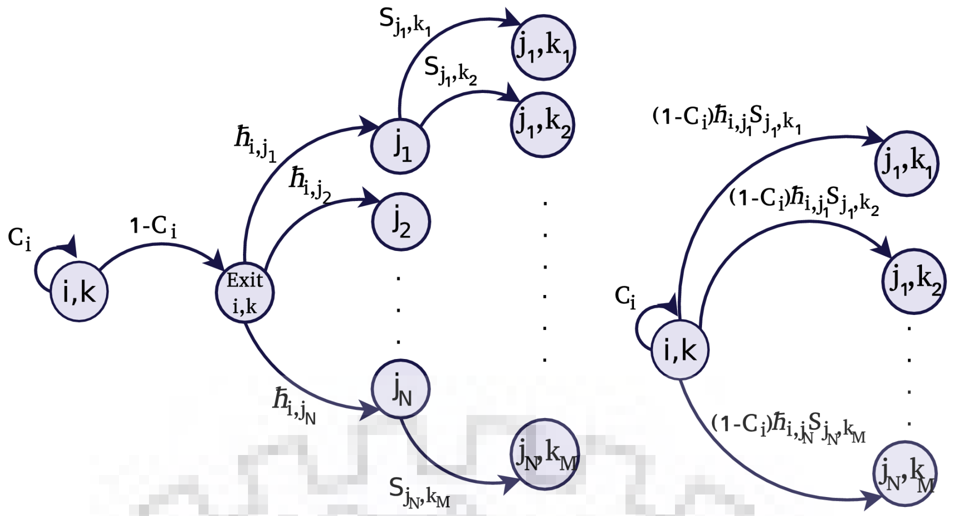


(a) (b)

Fig. 4.5. Example for the analysis [3]

All the likely TALs for Fig. 4.5 are:

$\Gamma = \{\{\eta_1\}, \{\eta_2\}, \{\eta_3\}, \{\eta_1, \eta_2\}, \{\eta_1, \eta_3\}, \{\eta_2, \eta_3\}, \{\eta_1, \eta_2, \eta_3\}\}.$



(a) Embedded Markov chain

(b) Embedded Markov chain with aggregated states

Fig. 4.6. Embedded Markov chain [3]

Also, the offline solution generates a matrix and consider S as given below:

$$\mathcal{S} = \begin{bmatrix} 0.3 & 0 & 0 & 0.2 & 0.5 & 0 & 0 \\ 0 & 0.3 & 0 & 0.3 & 0 & 0 & 0.4 \\ 0 & 0 & 0 & 0 & 0.1 & 0.4 & 0.5 \end{bmatrix}$$

Suppose that the probability of the mobility of UEs is meant by Y and it very well may be reasoned from $\hat{Y}$. All components $y_{m,n}$ in Y can be determined as mentioned below:

$$\forall m \in \hat{\mathcal{L}}, \hat{y}_{m,n} = \frac{y_{m,n}}{\sum\limits_{\forall n \in \hat{\mathcal{L}}} y_{m,n}} \tag{4.47}$$

Each element N_m in N represents the time that the UE can spend in site m. N_m can be computed as follow:

$$\forall m \in \hat{\mathcal{L}}, N_m = \frac{\sum\limits_{\forall n \in \hat{U}} \mathcal{N}_{m,n}}{|\hat{U}|} \tag{4.48}$$

Fig. 4.6 shows two occasions that lead to leave a state (m, k) in EMC and Fig. 4.7 demonstrates the relating Embedded Markov Chain of the system topology shown in Fig. 4.5.

- The likelihood for incoming call arrival before the user leaves its current state m is:

$$C_m = P(\mathcal{T} < N_m) = \lambda/(\lambda + \mu_m) \tag{4.49}$$

- The likelihood for the user to leave its TA m before the call arrival is:

$$1 - C_m = P(N_m \leq \mathcal{T}) = \mu_m/(\lambda + \mu_m) \tag{4.50}$$

The EMC shown in Fig. 4.6(a) can be decreased by gathering its states to another EMC as appeared in Fig. 4.6(b). When a user, is allotted TAL t_l, moves from TA m to another n, two sorts of events can occur:

- TA n has a place with TAL k.
- TA n does not have a place with TAL k

Let $A_{m,n,k}$ and $B_{m,n,k}$ denote the likelihood of the first and the second events, separately. Also, $A_{m,n,k}$ and $B_{m,n,k}$ denote the probabilities of moving from TA m to another TA n and after that choosing TAL k.

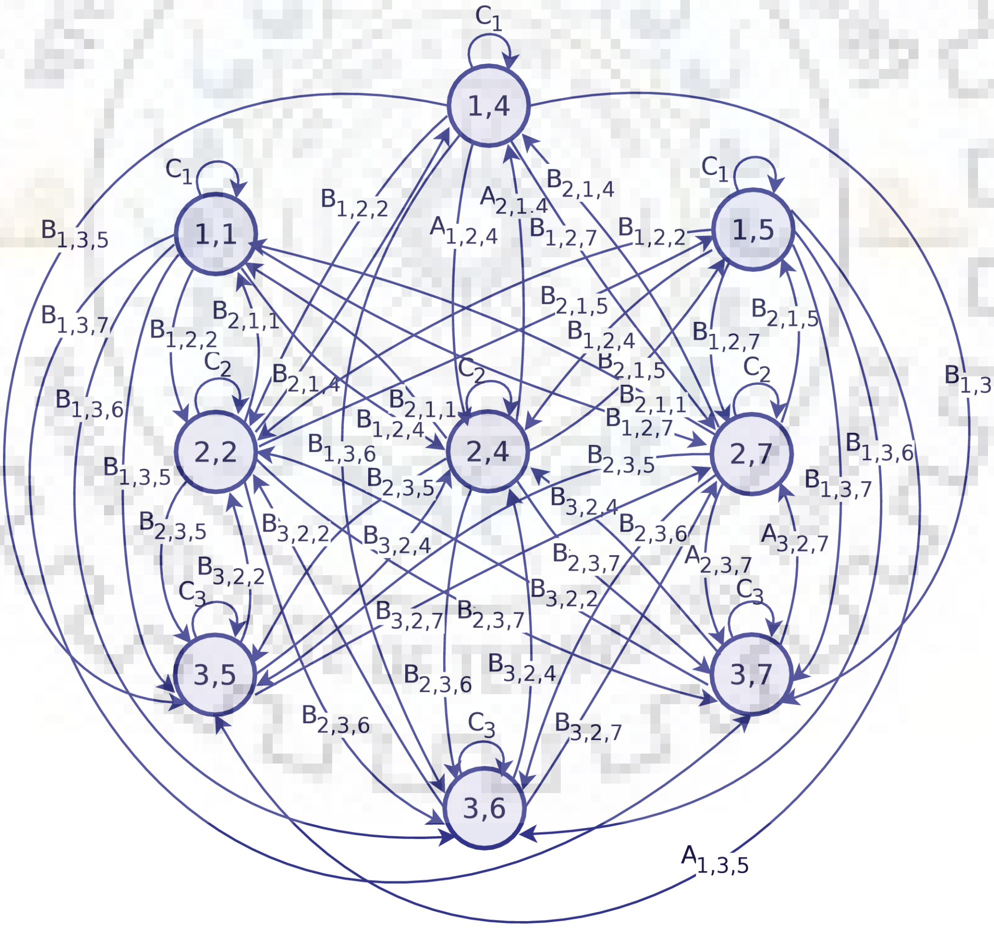


Fig. 4.7. Embedded Markov model [3]

$$A_{m,n,k} = Pr(\mathcal{T} > N_m)\hat{y}_{m,n}\mathcal{S}_{nk} \tag{4.51}$$

$$B_{m,n,k} = Pr(\mathcal{T} > N_m)\hat{y}_{m,n}\mathcal{S}_{nk} \tag{4.52}$$

$$C_m = Pr(\mathcal{T} < N_m).\ \forall m \in \hat{\mathcal{L}} \tag{4.53}$$

4.5 Performance Evaluation

The deployed zone is separated into a lot of TAs, where each TA has a rectangular shape with a particular length and width. TAs may have various surfaces as per their length and width. The versatility of UEs is displayed by the Random Waypoint Mobility Model [2] with the respite time sets to zero. The assessment is begun by setting each UE in a given TA.

Fig. 4.8 displays the numerical outcomes, concentrating on the effect of TAU and paging overhead on every arrangement by changing λ, the normal proportion of requires a user in the system. Now, λ is shifted from 1 to 10 while μ_i is fixed to 5. The overheads for every arrangement are assessed utilizing the accompanying equations:

$$Overhead_{TAU} = O^{TAU}(N_{TAU}) \tag{4.54}$$

$$Overhead_{paging} = O^{paging}(N_{paging}) \tag{4.55}$$

$$TotalOverhead = Overhead_{TAU} + Overhead_{paging} \tag{4.56}$$

where, N_{TAU} and N_{paging} denotes the number of TAUs and number of users paged respectively.

Table 4.1 gives the performance of the total signalling overhead for the three solutions (TAU, paging and tradeoff) as λ varies. Numerical results show that FOTA results in a fair tradeoff.

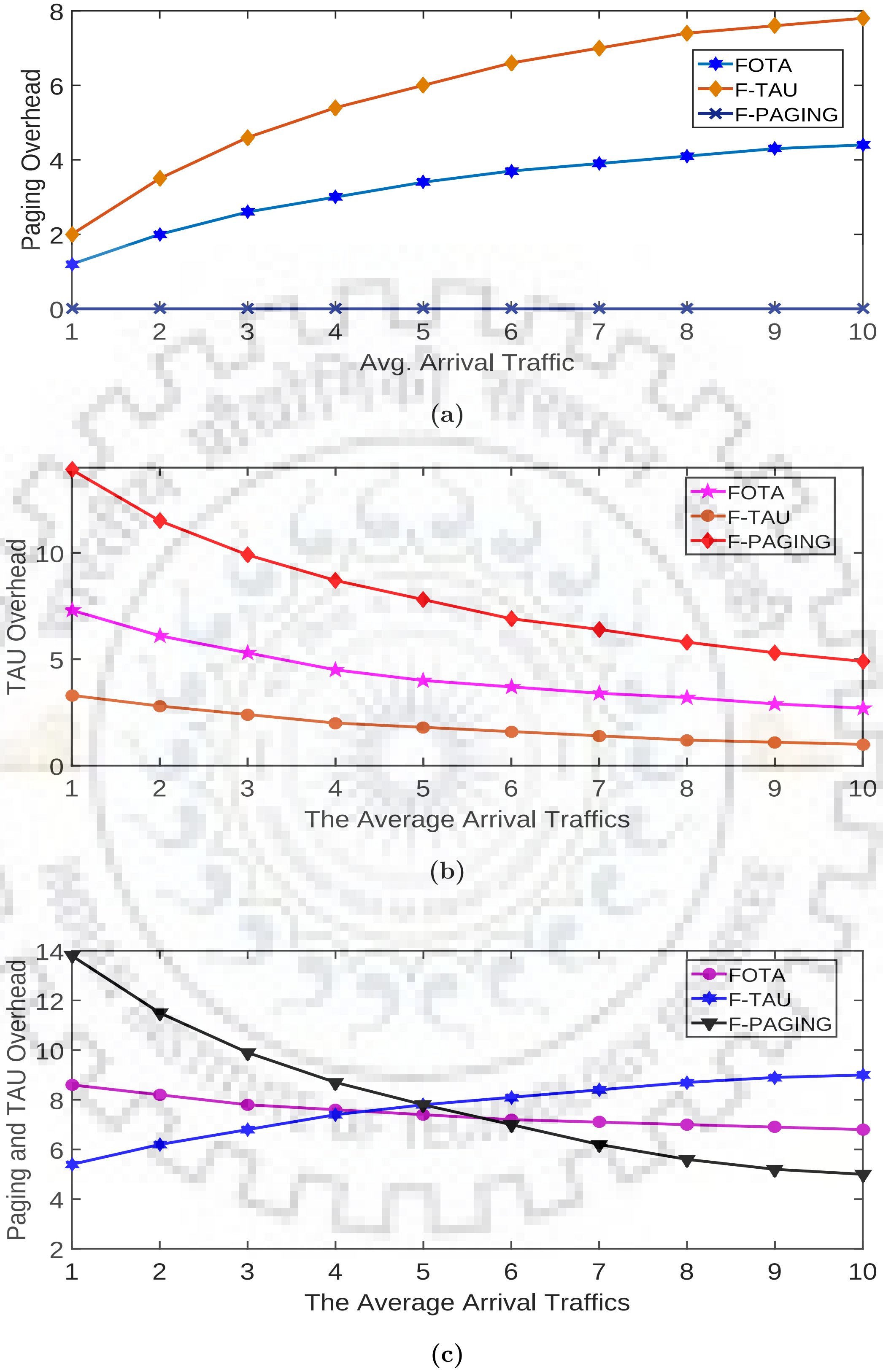


Fig. 4.8. Performance as a function of λ (a) Paging overhead; (b) TAU overhead; (c) Paging and TAU overhead

Table 4.1: Total signalling cost vs λ

Solution	**Performance**
F-TAU	Best performance for $\lambda < 5$
F-Paging	Better performance for the values of $\lambda > 5$
FOTA	Attains a fair tradeoff

Table 4.2: Percentage reduction in the cost for user's priority

Parameter	**F-TAU**	**FOTA**	**F-Paging**
PAGING Cost			
Low Speed 10 km/h	5.6%	10.2%	5.1%
Medium Speed 40 km/h	5.28%	10.2%	5.1%
High Speed 90 km/h	5.56%	10.2%	5.1%
TAU Cost			
Low Speed 10 km/h	2.5%	5.1%	5.1%
Medium Speed 40 km/h	2.2%	2.5%	4.1%
High Speed 90 km/h	1.9%	1.5%	2.5%
Overall Cost			
Low Speed 10 km/h	7.7%	9.1%	5.1%
Medium Speed 40 km/h	7.8%	8.1%	2.12%
High Speed 90 km/h	7.6%	6.2%	1.2%

The offline methods are assessed through simulations done in Matlab. The framework is assessed through the simulating the three offline and the two online solutions resulting six potential mixes of convention. The handover data between various TAs is sent from the online to the offline advance. Amid the movement of a UE, a TAU message is produced and sent to MME each time a UE crosses a TA that does not belong to the TAL in the online advance. The improvement issues are explained considering various estimations of the normal speed of UEs and the normal proportion of calls of each UE in the system.

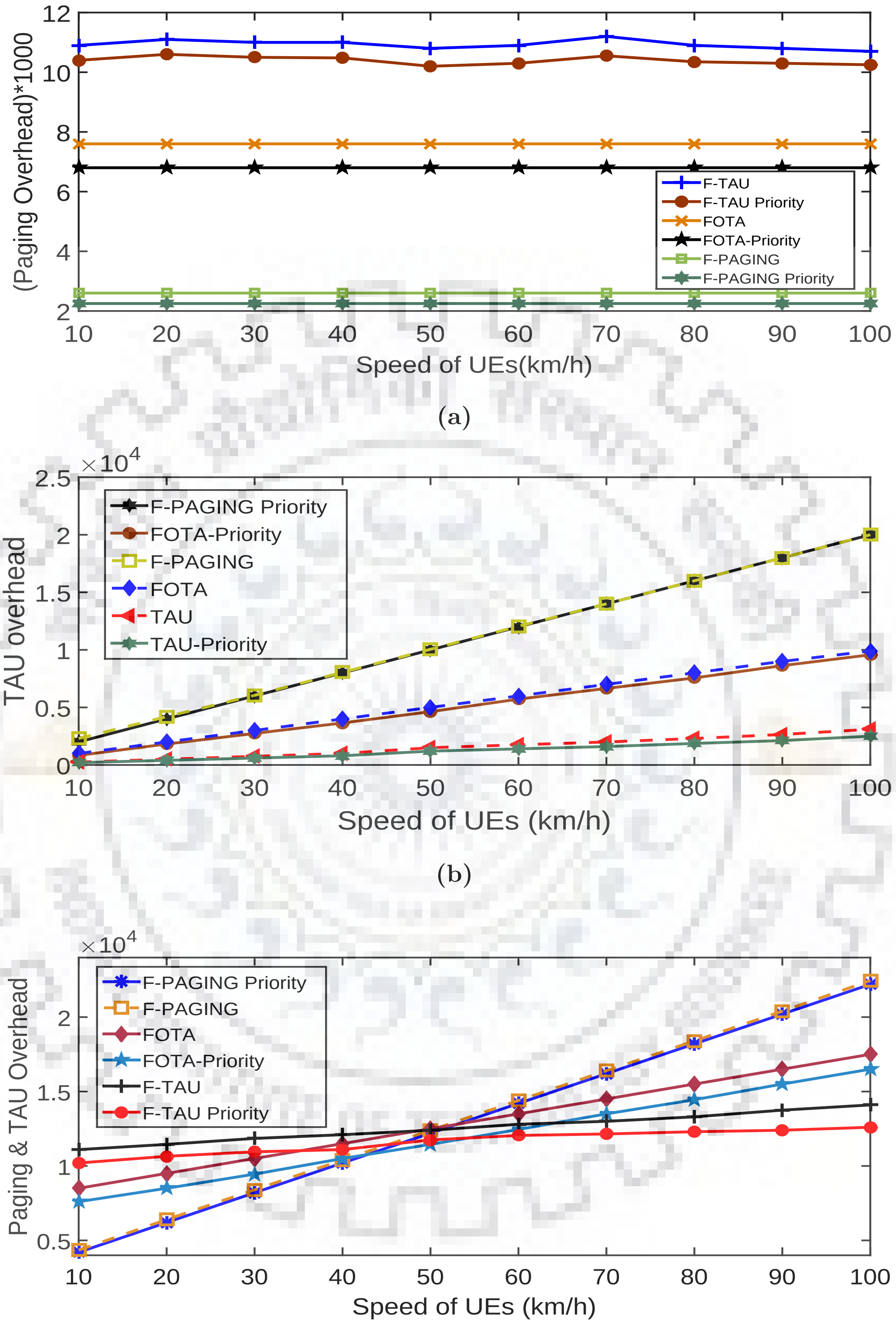
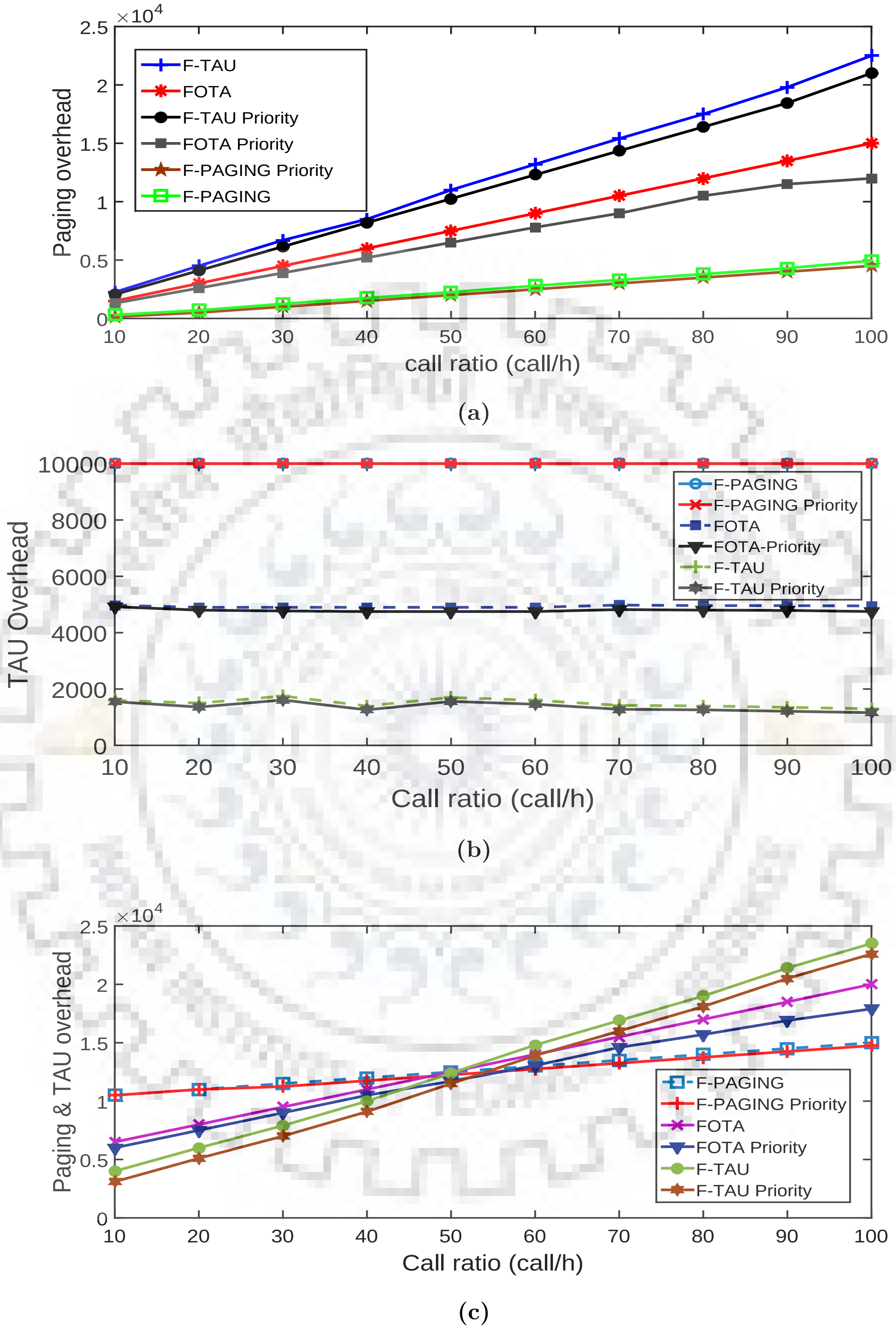


Fig. 4.9. Signalling cost vs speed of users (a) Paging overhead; (b) TAU overhead; (c) Paging and TAU overhead

Table 4.2 demonstrates the percentage reduction in the cost of the network considering the priority of UEs.

Fig. 4.9 demonstrates that F-Paging gives better performance for the speed of UEs less than 50 km/h and F-TAU is having low cost if the speed of UE surpasses 50 km/h. Fig. 4.10 demonstrates that F-TAU gives better performance for the call ratio below 50 calls/h and F-Paging is having low cost for the call ratio is greater than 50 calls/h. Fig. 4.9(c) and Fig. 4.10(c) represent the trade-off accomplished by FOTA between TAU and paging overhead. They demonstrate the complete overhead brought about in the three arrangements for various estimations of the UE speed and call proportion, separately. It is likewise seen that FOTA performs comparatively to F-TAU when the call proportion does not surpass 50 calls/h or the speed of UEs surpasses 50 km/h. The exhibition of FOTA is between F-TAU and F-PAGING, contingent upon the UEs' speed and their movement levels (i.e., call rate). For very versatile UEs, FOTA performs like F-TAU (ideal) and superior to F-PAGING, while for profoundly dynamic UEs, FOTA performs like F-PAGING (ideal) and superior to F-TAU.



(a)

(b)

(c)

Fig. 4.10. Signalling cost vs call ratio (a) Paging overhead; (b) TAU overhead; (c) Paging and TAU overhead

Chapter 5

Comparative Analysis of 5G Architectures

5.1 Proposed Clustering Algorithm

To form cluster heads (CHs), three parameters are used as the inputs of the algorithm including residual energy of the UEs, density of the UEs and their position in the clusters. Also, distance of the nodes from the base stations (NBs) is also used [13-15]. The clustering algorithm of the UE is divided into three parts namely, Uniformly Distributed Clustering Algorithms (UDCA) - UDCA1, UDCA2 and UDCA3. UDCA1 (NSA-CH) is Uniformly Distributed Dynamic Clustering Algorithm. UDCA1 is used for the NSA network that will use the existing LTE core networks infrastructure. UDCA2 (SA-CH) is Uniformly Distributed Static Clustering Algorithm in which static active nodes (ANs) will be deployed. The static ANs will form clusters with the mobile UEs as well as stationary IoT devices and small 5G cells (pico and femto cells) will be deployed for this scenario. UDCA3 (Hybrid-CH) is the hybrid of both the SA and NSA architecture. Density of UEs in a particular zone will be an important criteria to decide whether there is a need to form CHs among the UEs depending on the energy level and distance from the Cluster Members (CMs) or static ANs need to be deployed in a particular zone. Unification of 5G and 4G layers is shown in Fig. 5.1.

Paging overhead reduces because of the cluster formation the MME directly page to the CHs or ANs in the granularity of TA. In this case, only factors involved are battery life or energy of the UEs and the connectivity factor because by forming CHs energy of the UEs will also suffer. Therefore, a hybrid scheme of both the proposed algorithm gives

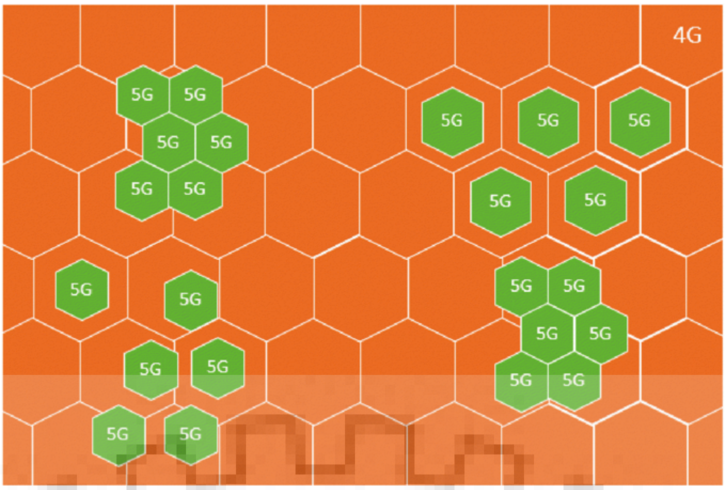


Fig. 5.1. Unification of TAs [4]

the relatively better results for both the factors (signalling overhead and energy of UEs).

Clustering algorithms have been proposed and accepted widely to reduce the energy consumption. Clustering is an effective approach to deal with network congestion and energy efficiency concerns. In this thesis, clustering algorithm is used to improve the network performance with reduced signalling overhead, consisting of two conflicting metrics namely Paging Overhead and TAU overhead. Also, communication (routing overhead) while making clusters need to be taken into account in a deployed zone. Therefore, signalling overhead reduces at the cost of energy of the UEs. The proposed scheme has low routing overhead compared to the conventional scheme. Also, RWP model is defined for the variation in the position, speed, and direction of the UEs.

5.2 Formulation

In UDCA, the remaining energy and regional average remaining energy of UE in their cluster along with the regional associativity with other UEs are taken into account to designate CHs.

Regional average residual energy:

$$R_{E_{av}} = \sum U_{E_i}/N_R \tag{5.1}$$

Regional average measure of associativity with cluster nodes:

$$R_{MoA} = \sum M(i)/N_R \tag{5.2}$$

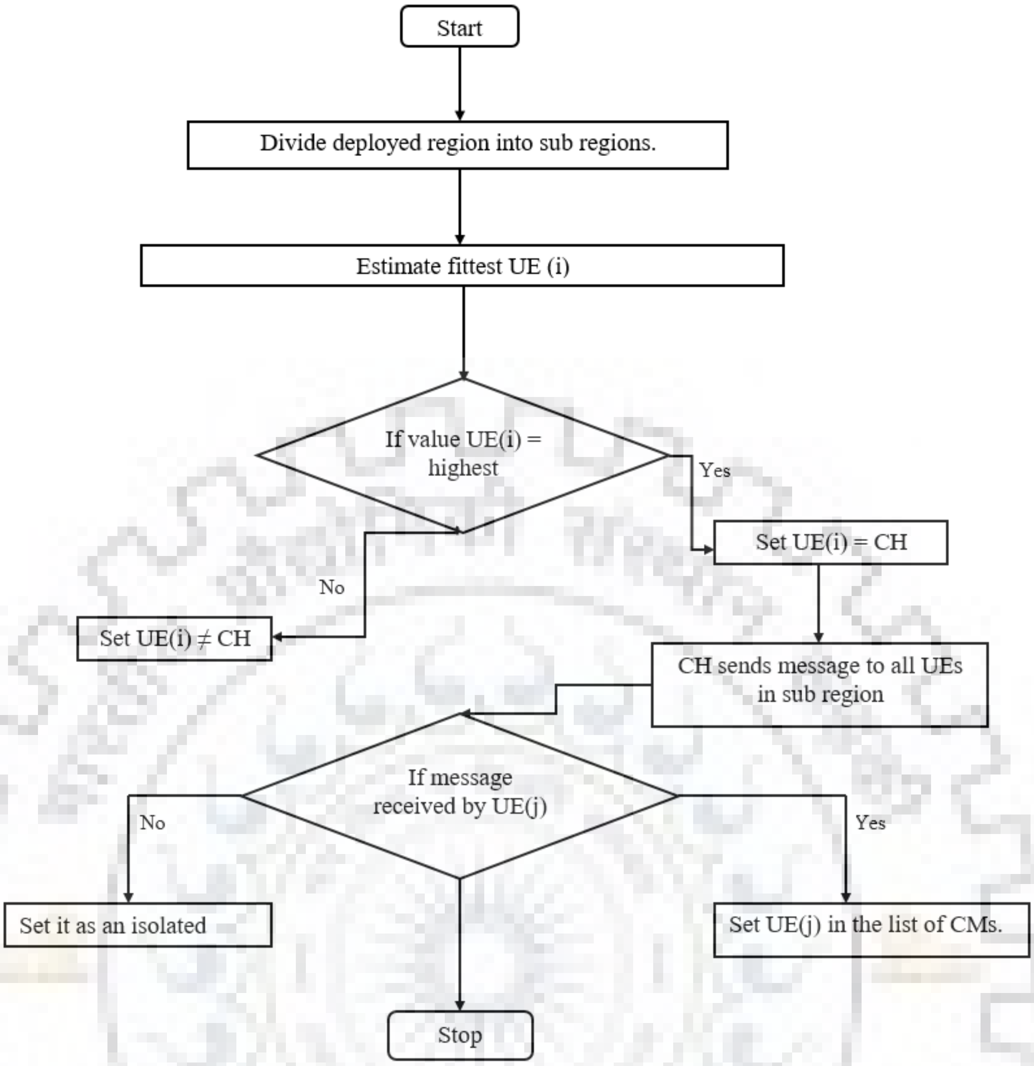


Fig. 5.2. Flowchart of UE's clustering algorithm

where, $M(i)$ = Measure of associativity of i^{th} node of the sub region.

$$Fitnessvalue(i) = A_w(M(i)/R_{MoA}) + E_w(U_{E_i}/R_{E_{av}}) \tag{5.3}$$

where, A_w represents the weight for associativity of UE to NB and E_w represents the weight for energy.

As per proposed UE's clustering algorithm shown in Fig. 5.2, the node having best fitness value of R_{Eav} and R_{MoA} will be considered as CHs. After dividing the whole area into regions and clusters, there will be some isolated UEs. These UEs will directly connect with the NBs depending on their range and form cluster among isolated UEs.

The clusters are formed by considering the communication range 'R' of the node in the network:

```
if dis(q,q+1)< R then
    Strat cluster formation;
    Communicate with NB via CH;
else
    Communicate with NB directly;
end if
```

Let us suppose that the set of NBs in a network is defined by $\hat{S} = [1, 2, ..., S]$, and the set of TAs is defined as $\hat{P} = [1, 2, ..., P]$. The vector $\mathbf{x} = [x_1, x_2, ..., x_C]$ is used for cell-to-TA assignment, where x_m represents the TA of cell m. The TA design $\mathbf{x}$ can be represented by a $S \times S$ symmetric and binary matrix $Y(\mathbf{x})$. The element $y_{mn}(\mathbf{x})$ is defined as:

$$y_{mn}(\mathbf{x}) = \begin{cases} 1 \ ; & \text{if} \ \ x_m = x_n \\ 0 \ ; & \text{otherwise} \end{cases} \tag{5.4}$$

The cost factor TAU of site m is proportional to the number of UEs moving from NB m to the other NB n, when m and n are in different TAs, *i.e.*

$$C_{TAU} = \sum_{m \in \hat{S}} \sum_{n \in \hat{S}: m \neq n} C^{STAU} z_{mn}(1 - y_{mn}(\mathbf{x})) \tag{5.5}$$

Paging cost is propotional to the the UEs present in a given site, *i.e.*

$$C_{Paging} = \sum_{m \in \hat{S}} \sum_{n \in \hat{S}: m \neq n} \alpha N_{ue} C^{P} y_{mn}(\mathbf{x}) \tag{5.6}$$

Assume that N_{CH} denote the number of CHs in a site m and N_{CM} denote the number of cluster members (CMs), member in the list of the head of CH. CHs will be having the list of it's CMs and the list gets updated routinely depending on the factors like degree of connectivity, density of CMs and distance among the CMs in a site. Paging cost is reformulated as follows:

$$C_{Paging} = \sum_{m \in \hat{S}} \sum_{n \in \hat{S}: m \neq n} C^{CM} N_{CM} y_{mn}(\mathbf{x}) \tag{5.7}$$

Assume that $C_{overall}$ denotes the overall cost of the network which is given as:

$$C_{overall} = C_{TAU} + C_{Paging} \tag{5.8}$$

5.3 Simulation Results

Deployed network as shown in Fig. 5.3 is a hybrid of NSA and SA architecture. Depending on the requirement of UEs, the network is deployed with random distribution of macro cells and small cells (micro cells, pico cells and femto cells). Brown marks at the centre of the cell are eNodeBs (macro Cell) that already exist in LTE network. Blue and green dots represent newly deployed small cells with small coverage. Red nodes represent randomly distributed UEs. Assume that the complete site is covered by seven macro cells as shown in Fig 5.3. These cells will form a set of TAs and a list of TA will be assigned to the UEs depending on their mobility pattern so as to reduce the signalling cost of the network. As shown in Fig. 5.4, UEs form clusters depending on the RSS and distance from the ANs or SCs. ANs will contain the list of all the UEs as CMs. Therefore, paging cost will get reduced in this case as MME will send paging request to ANs in a given TA, and the UE which is a CM will get paged directly. The simulation study is carried out in

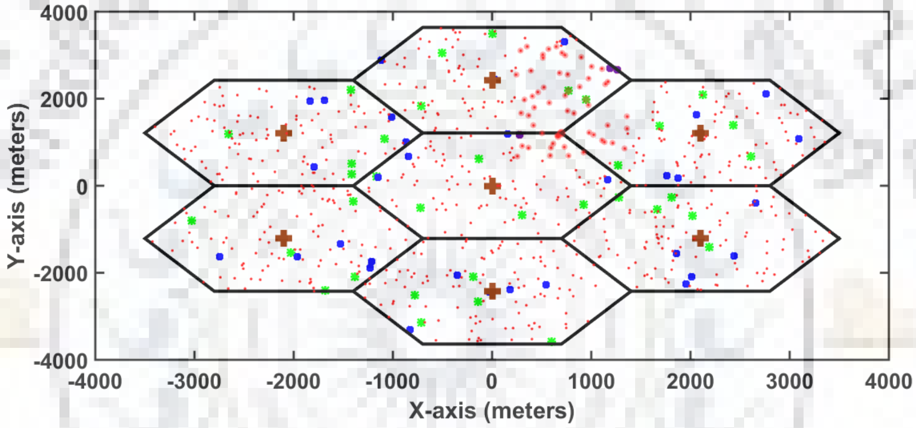


Fig. 5.3. UE's random walk

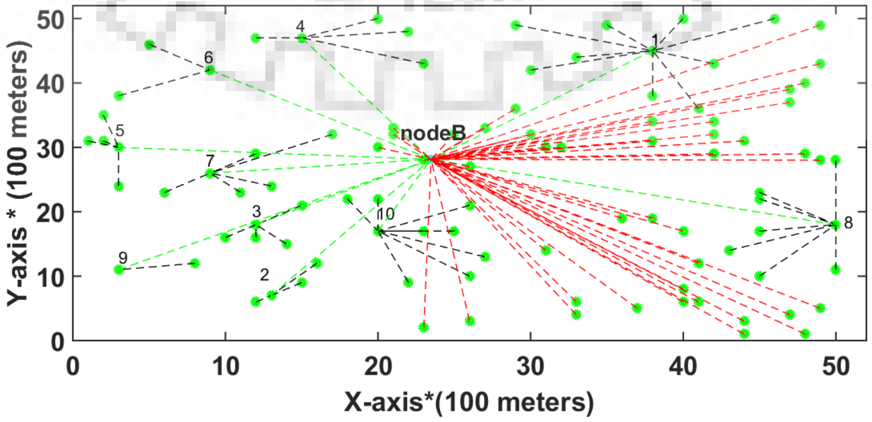
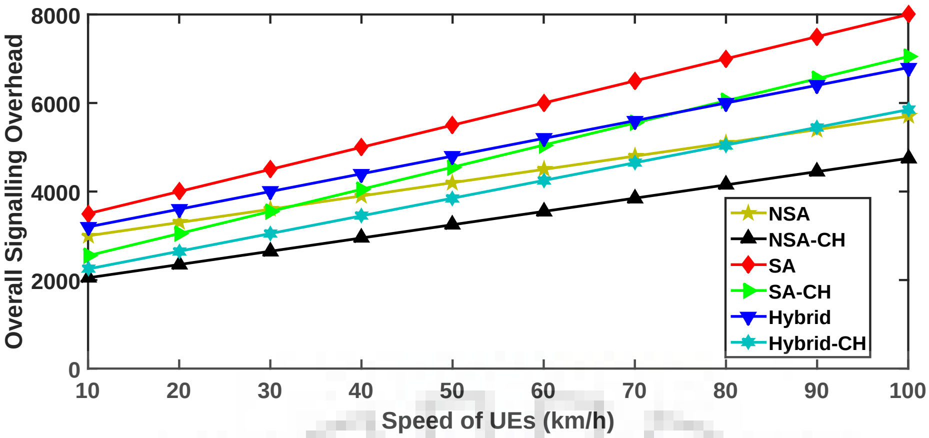
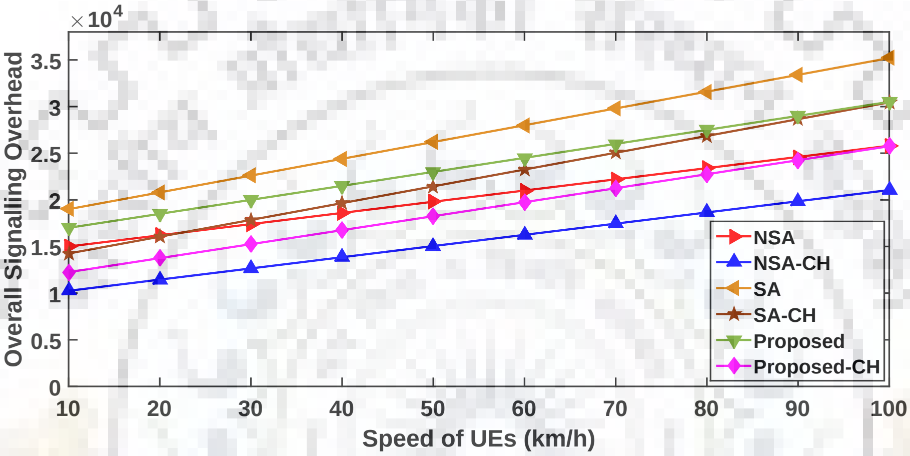


Fig. 5.4. Cluster formation



(a)



(b)

Fig. 5.5. Comparison of overall signalling overhead with and without cluster formation (a) For 100 UEs; (b) For 500 UEs

Matlab environment. Simulation results show that for the hybrid case, overall signalling overhead cost reduces with the increasing number of UEs. For the case when the number of UEs in a given region are small, the paging cost is small compared to the case with more cells and UEs in a given TA. Therefore, NSA architecture gives better result for low density of UEs. Fig. 5.3 shows the model for mobility of UEs. Dots marked in Fig. 5.3 are UEs, moving freely in different directions with different speeds. The list of TAs assigned to UEs and cluster formation of nodes will be dependent on UE's mobility pattern. Frequently visited nodes by UEs need to be a part of the same TA, to reduce the TAU cost. Considering the second scenario in which UEs are not that mobile, more UEs are idle in a given TA. Therefore, paging cost will be more as nodes form a large cluster. The proposed technique based on game theory finds the solution that provides a fair trade-off between these two conflicting objectives (TAU overhead and paging cost).

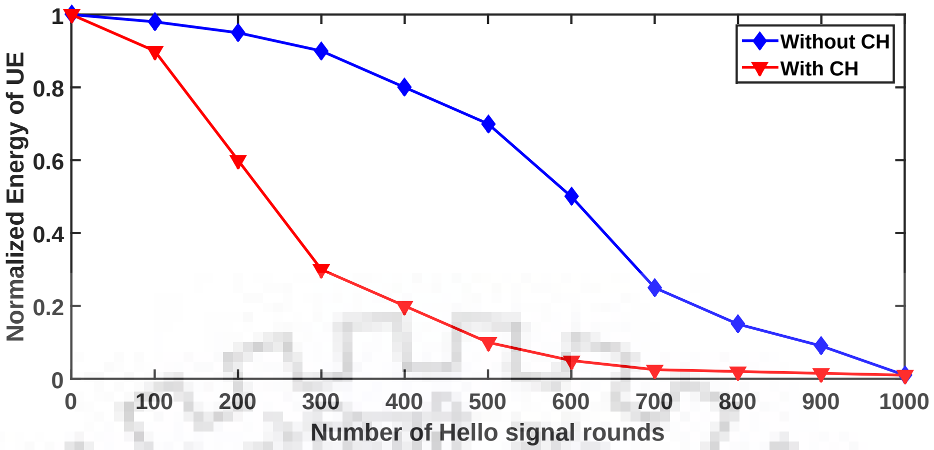


Fig. 5.6. Normalized energy of UEs vs time

The movement of UEs for the simulation purpose is governed in a manner that each dot (UE) moves to a new position depending on the speed which is randomly chosen between 0 (excluded) and some maximum speed. As shown in Fig. 5.5, the overall signaling overhead increases as the speed of the UEs increases. As shown in Fig. 5.5(a), for 100 UEs scenario SA architecture will be having highest overall signaling overhead . This is because of huge TAU cost involved in this case relative to the others. Also, NSA-CH architecture results in the best performance for the overall signaling overhead. The reason for the same is that relatively low TAU cost is involved and low paging cost because of cluster formation. Below 30 km/h, the cost of SA-CH architecture is smaller compared to Hybrid and NSA architecture. But as the speed of UEs crosses 30 km/h, cost of NSA architecture reduces and is less compared to the Hybrid architecture. The reason for the same is that for Hybrid architecture UEs will have TAU while moving between two different network layers (4G and 5G). If the speed of UE increases furher and crosses 80 km/h, the overall signaling overhead cost of SA-CH architecture will be more relative to the Hybrid architecture because of huge TAU cost involved within the small cell boundaries of SA case. Let us consider the case when the number of UEs increased to 500. As shown in Fig. 5.4(b), when the speed UEs is below 25 km/h SA-CH architecture performs better than NSA architecture. When the speed of UE increases further and crosses 25 km/h, SA-CH perform better than NSA.

As mentioned in Table 5.1, clustering of UEs reduces the overall overhead of the deployed network, and results in very good percentage reduction in the overall signalling cost. The signaling overhead is reduced at the cost of energy (battery consumption) of

Table 5.1: Percentage reduction in the overall cost using UE's clustering algorithm

Parameter	**SA**	**NSA**	**Proposed**
For 100 UEs			
Low Speed 10 km/h	33.36%	51.2%	45.45%
Medium Speed 50 km/h	25%	40.2%	33.3%
High Speed 90 km/h	16.38%	27%	20.8%
For 500 UEs			
Low Speed 10 km/h	33.3%	50%	40%
Medium Speed 50 km/h	25.6%	40%	31.25%
High Speed 90 km/h	17.6%	33.3%	21.2%

the UEs. as the UE sends messages regularly. The variation in the normalized energy of UEs with respect to time is shown in Fig. 5.5. From the above discussion, it is clear that in case of SA architecture proposed in 3GPP release 15 there will be huge TAU cost involved because of small cell sites, and for NSA architecture relatively lowest overall signaling overhead is involved. To achieve the objectives of 5G small cells need to be deployed. Therefore, the proposed hybrid case results in a tradeoff, and is practically relevant for the initial rollout of the 5G network.

Chapter 6

Conclusion and Future Scope

This thesis focuses on reducing the overall signalling cost for the 5G networks by employing game theory for TA reconfiguraion, optimization techniques for allotment of TA to TAL, and finally compares various proposed architecture for the upcoming 5G cellular network. In LTE and upcoming 5G networks, the position of UEs and their mobility pattern change with respect to time. Therefore, there is a need to design the TA in such a way that it is able to adapt to the variations in the position of UEs with minimum reconfiguration cost. In comparison to the genetic algorithm (GA) based TA planning, the proposed method leads to lower signalling cost and more flexible TA design. The simulation results show that as the reconfiguration cost increases for the network with less number of TAs, overall signalling cost reduces as the cost incurred towards TAU gets reduced. The proposed approach leads to approximately 18 to 24 percent reduction in the overall signalling overhead of the network. Also, Markov based model is employed to study the offline solutions for the assignment of TA to TAL, and it is observed that FOTA gives satisfactory results. For the upcoming 5G networks, the number of smart devices will increase which will increase the signalling overhead cost for a given network and deteriorate the overall performance of the network. Therefore, to cope up with this situation, this thesis proposes the use of clustering algorithm alongwith the unification of the two network layers for the initial roll out of the 5G networks. Comparative results show that the Hybrid-CH provides the satisfactory results, and is more suitable for the initial deployment.

As a future work, the proposed algorithm can be used further for URLLC communications. Also, machine learning can be used for the TA reconfiguration.

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