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IMPACT OF DWELL TIME DISTRIBUTION ON LOCATION MANAGEMENT IN CELLULAR NETWORKS

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Abstract

This paper presents dwell time distribution based optimal reporting cell planning (RCP) for location management in wireless cellular networks. Dwell time parameter is critically dependent on users' behavior within the network. The innate advantage of Percentile dwell time over the conventionally used absolute dwell time is that it can take only fixed values depending on the number of cells per location area. This helps tremendously in reducing the computational overhead and can be applied to any size of the network as long as the number of cells per location area remains constant. Consequently, the proposed percentile dwell time has been used to determine the optimal reporting cell-planning configuration such that the overall mobility management cost is minimized. Evidently, from the simulation result the proposed technique provides a clear edge of 14.28% improvement in cost reduction compared to the existing technique.

Keywords: Dwell time, Location area, Location management, Mobility management, Percentile dwell time, Reporting cell planning, Sojourn time.

1. Introduction

Location Management is the tracking of current location of mobile users in a cellular network [1]. It also deals with minimizing cost and overhead associated with the process. It broadly consists of two processes: Location Update and Paging [2]. In some research works, Location Update is also referred to as 'Registration' or 'Location Registration', whereas, Paging is also referred to as 'Location Lookup' or 'Search' [3]. Location Update is performed by the User Equipment which informs the network of the user's current location. Paging is performed by the Base Station which polls a group of cells to determine the precise location of the user. Location area (LA) is a group of one or more cells within which no location update

Nomenclatures

CostLU	Location update cost
M	Number of location areas in a network
N	Number of cells in a cellular network
N_{LU}	Total number of location updates
N_P	Total number of paging performed
N	Number of cells per LA
T_d	Dwell time
T_{d_h}	Handover call dwell time
T_{d_max}	Maximum dwell time
T_{d_n}	New call dwell time
T_{LA}	Dwelling time within the current LA
T_{pd}	Percentile dwell time

Greek Symbols

β	Weight factor associated with location update cost
Λ	Call rate

Abbreviations

LA	Location Area
LM	Location Management
LU	Location Update
nRC	Non-Reporting Cell
RC	Reporting Cell
RCP	Reporting Cell Planning

occurs, whereas Reporting Cell (RC) is a group of one or more cells only within which location update occurs [4]. Almeida-Luz et al. concepts differ in subtle ways.

In a similar fashion, Location Update and Handoff are different in the sense that when the Mobile User changes a cell, it is called Handoff [5]. When the user changes Location Area, it is called Location Update. In context of Location Management, another term crops up, called Mobility Management [6]. Mobility Management is a larger concept, which may be broadly divided into two categories: Location Management and Handoff Management [7].

The paper organization is as follows. In tSection 2, the existing location management schemes have been briefly mentioned. Section 3 introduces the concept of Dwell Time Distribution parameter and introduces the new concept of Percentile Dwell Time Distribution. Section 4 provides the simulation results of three different network scenarios by incorporating percentile-dwell-time distribution along with Location Area to predict possible reporting cell planning (RCP) configuration. Finally, the discussion and conclusion are outlined in Sections 5 and 6, respectively.

2. Location Management in Cellular Networks

Cellular networks all over the world are overburdened with ever increasing subscribers' base. Every call made by the user involves both cost and computation power. In this regard, there seems to be an easier way to just calculate the dwell time parameter, so that the network can estimate the average amount of time a user remains in a cell. Once dwell time parameter is calculated, the network can decide where it can curtail location update procedure and thus save cost and burden. The broad objective of the work is to optimize both the cost of location update as well as registration to yield lower latency and network load. Here the performance of the cellular networks shall be evaluated considering dwell time as a key parameter for mobility management.

2.1. Location management techniques

(a) Location management is broadly classified into Update and Lookup.

(b) Location Update may be Static or Dynamic, based on the whether it is affected.

(c) Location Lookup' or 'Search'. Location Update is performed by the User If the Update procedure is Static, it is independent of the user movement behaviour, and vice- versa for Dynamic procedure.

(d) Location Lookup may be performed in a Sequential or Simultaneous manner, or by combining both to provide some degree of intelligence.

2.2. Static and dynamic Location Area (LA)

Location Area may be broadly classified as Static and Dynamic Location Area. Static LA means a well-defined shape and size of LA The cells under one LA stick to the same LA no matter what change in parameters occurs. In Dynamic LA bears any random shape and/or size depending upon various parameters. The cells under one LA at a particular moment may cling to another LA at the next moment.

From the literature, one can vaguely say that Static LA are simple and cost effective while deploying, whereas the L.M cost minimization may not be very optimal. On the other hand, Dynamic LA represent an improvement in L.M cost optimization although their deployment is expensive. This holds true especially during rush hour when the advantages of Dynamic LA become more pronounced [8-10].

Thus, a network with N cells can be divided into several disjoint location areas such that:

$$L.A_i \cap L.A_j = \emptyset \ \ \forall\, i,j \in N \tag{1}$$

and $\cup_{i=1}^{P} LA_i = Area(N)$ (2)

Or, a network can be divided into Reporting Cells (RC) [11] and Non-Reporting Cells (nRC) such that

$$RC \cap nRC = \emptyset \tag{3}$$

And $\sum RC + \sum nRC = Area(N)$ (4)

3. Dwell Time Distribution

3.1. Dwell time

Dwell time (T_d) is a random variable that describes the amount of time that a mobile can maintain a satisfactory two-way communication link, or simply that a mobile remains in a cell. It is also known as Cell-Residence Time or Mobile Sojourn Time [12-31]. Unit of Dwell time is seconds. Dwell time may be fed to the network on a

- Per-user basis,
- Per-cell basis,
- Time of the day based.

Dwell time may be broadly classified as shown in Fig. 1.

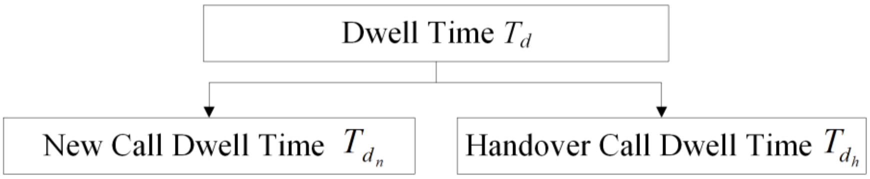


Fig. 1. Categories of dwell time.

New Call Dwell time (T_{dn}) is the time spent in the cell in which the call originates, whereas Handover Call Dwell Time (T_{dh}) is the time spent in the cell to which the call gets handed off. The sum of these two dwell times gives rise to Session Time, which is the entire duration of the call that may cover multiple cells. In the literature, several successful attempts have been taken to model the Dwell time distribution.

3.2. Issue identification

Most of the works related to location management in cellular networks have either concentrated on the total cost optimization or on parameters such as paging delay, meta- heuristic algorithms etc. However, if relative performance of each network with respect to time is considered, then it may be possible to improve their performance further.

This gives birth to the issue of Dwell Time Distribution. Cost function shall comprise of update cost and paging cost. Here, a factor of Percentile Dwell Time (T_{pd}) is proposed. Percentile represents the percentage of data which is below certain threshold.

This method of calculation differs from *percentage* values in the sense that percentage values need to be absolute whereas percentile settles for the relative ranking based on performance of other networks (or) the same network at different times of the day (or) the other users sharing the same network.

This method is especially important when the telecom companies are trying not to be the highest performing ones (as that would incur significant cost on the company side), but instead they just want to perform above the minimum threshold quality of service, relative to its worse counterparts.

So, when a person’s mobile handset tries to perform Location update, then instead of using Dwelling Time within the current LA (T_{LA}) as a parameter, the proposed “Percentile Dwell Time” (T_{pd}) shall be used, which is the percentage of dwell time below the dwell time in that cell.

Every radio transmission-reception involves power and hence cost. The importance of Location Management lies in reducing cost and load on the network by optimizing the cost function. The cost function as accepted by the most researchers is given by

$$Cost = \beta \times N_{LU} + N_P \tag{5}$$

where N_{LU} is the total number of location updates, N_P is the total number of paging performed and β is a constant to weigh the relative cost of LU compared to Paging.

Total cost of L.M is the sum of LU and Paging cost. Paging cost is simply call rate (λ) multiplied by the product of the number of cells and the cost per paging message. LU cost is the cost per LU divided by dwelling time within the current LA.

Here, it shall be seen how Percentile Dwell Time is useful in obtaining a possible set of Reporting Cells Configuration in a network. To recap, Reporting Cells (R.C) make it possible for the network to demarcate a particular set of cells, usually lying on the edge of any LA, such that a mobile user instantly updates its location information to the base station upon entering an R.C.

The advantage of T_{pd} based LU over traditional LA based LU is that in traditional LA based LU, an LU is triggered simply upon boundary crossing from one LA to another. This may lead to unnecessary LU cost if the user constantly hops from one LA to another (assuming that the user is moving along the LA boundary). But in T_{pd} based LU, only specific cells are assigned as R.C depending on the user's movement pattern. This avoids excessive LU cost by triggering a LU only when the user enters an R.C.

By accurately predicting the Reporting Cells in a network according to the percentile dwell time distribution, the total number of R.Cs shall be optimized as per the user. Therefore, it is expected that unnecessary location updates shall be minimized, yielding lower mobility management cost.

3.3. Conceptual representation

When location update is performed from one to another LA (such as from cell 4 to cell 9), then the percentile dwell time is calculated as: cell 4 has dwell time 19 units. Number of cells whose dwell time is lower than 19 units within that LA is 3. Total no. of cells in blue LA is 7. So, percentile dwell time is given by

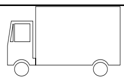
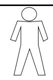
$$T_{pd} = \frac{3}{7} \times 100 = 42.857$$

The LU cost shall be calculated as:

$$Cost_{L.U} = \frac{Cost\ per\ L.U}{percentile\ dwell\ time} \tag{6}$$

In Eq. (6) above, the major parameter to be identified is that the denominator of the right-hand side of the equation has Percentile Dwell Time instead of the conventionally used (Absolute) dwell time. Analogy of the concept is shown in Table 1.

Table 1. Dwell time concept tabulation.

PARAMETER		
Speed	Fast	Slow
Expected Dwell Time	Low	High
Expected L. U. Cost	High	Low

The proposed parameter shall be given by:

$$Percentile\ dwell\ time = \frac{No.\ of\ cells\ with\ lower\ dwell\ time}{Total\ no. of\ cells\ in\ that\ L.A} \times 100 \tag{7}$$

The effect of this parameter change shall be observed by taking some sample networks and sample sets of data, to compare with standard results for validation. A clear representation of where the Percentile dwell time parameter settles into the scheme of things, is shown in Fig. 2 organogram:

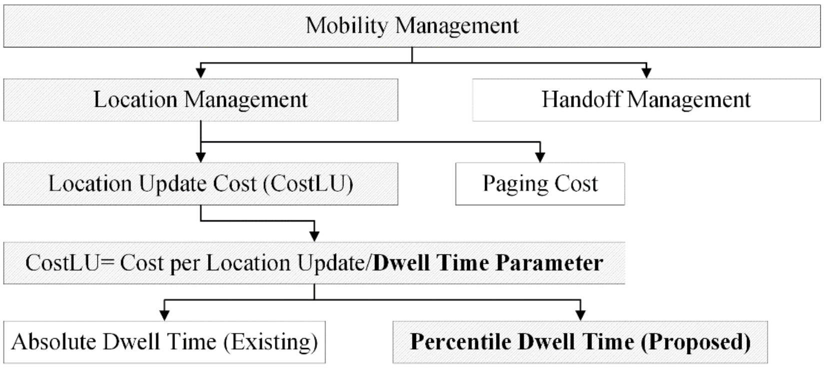


Fig. 2. Integration of the proposed T_{pd} in the denominator of location update cost.

3.4. Percentile dwell time for Reporting Cell Planning (RCP)

Assumptions:

a) Random Dwell Time Distribution has been assumed since it is the simplest to simulate and provides a foundation for further studies.

b) Fixed LA type (Static LA) is taken since most present networks utilize Static LA

c) For areas where overall mobility is expected to be lower (Household or residential areas), the expected Maximum Dwell Time (T_{d_max}) shall be higher whereas for areas with high mobility (highways) [31], T_{d_max} shall be lower.

Proposition:

The steps intended for calculating the T_{pd} matrix are as shown in Table 2.

The steps to predict Reporting Cell Planning using Percentile Dwell Time is mentioned in Table 3. The same is pictorially represented in Fig. 3.

Table 2. Algorithm to calculate T_{pd} matrix.

Step No.	Measures taken
1.	Define the size of the network, i.e., denote the number of LA as '*m*' and the number of cells per LA as '*n*'.
2.	Set a maximum limit for T_{d_max}.
3.	Generate an $m \times n$ matrix to describe the absolute dwell time distribution.
4.	Calculate the Percentile Dwell Time for each cell to produce an $m \times n$ matrix of percentile Dwell time distribution.
5.	Based on the above matrix, determine a possible set of reporting cells.
6.	Repeat steps a-e for various network sizes and different T_{d_max} values.

Table 3. Algorithm to predict RCP configuration.

Step No.	Measures taken
1.	Obtain the percentile dwell time matrix for an $m \times n$ network
2.	Assign the T_{pd} values to the cells of each Location Area according to the cell numbering sequence in the network topology. The sequence of filling up is as follows: • The T_{pd} matrix values are counted along left to right, top to bottom of the T_{pd} matrix. • The Location Areas are counted from left to right, top to bottom of a network topology. • The cell numbers are counted in outward spiral direction, starting from the central cell in every Location Area.
3.	Start with any cell of an LA which shares its boundary with another LA, and has lowest T_{pd} value. Assign this cell as an R.C.
4.	Look for the next cell which shares its boundary with the previous R.C. Of all these cells, assign R.C to that cell which has the lowest T_{pd} value and preferably belongs to a neighbour LA
5.	Repeat steps 2-4 till the edge of the network is reached, or the desired R.C.P is obtained.

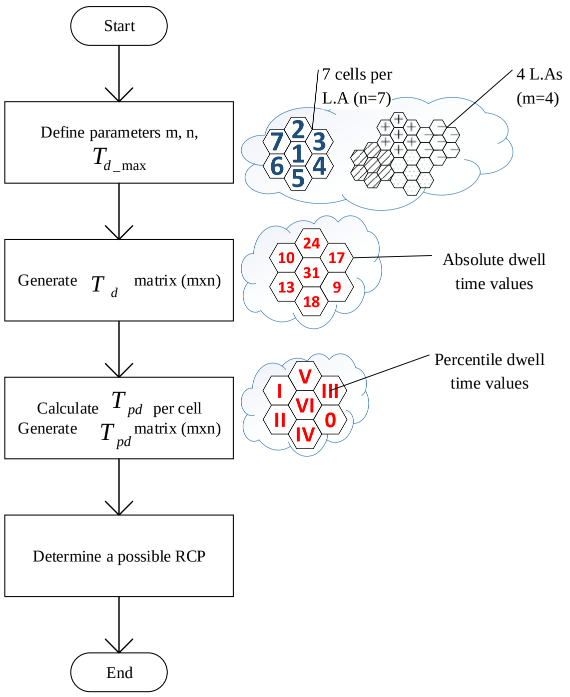


Fig. 3. Simulation sequence to predict possible RCP using percentile dwell time distribution.

4. Simulation Results

Simulations were performed in MATLAB based on the above model for a 4×7 ($m \times n$) network. The probable RCP was proposed based on a method similar to [32]. The sequence of representing the network topology has been illustrated in Table 4 and Fig. 4.

Table 4. Symbol notation in cell diagram.

Symbol	Percentile Dwell Time	Symbol	Percentile Dwell Time
0	0.00	*IV*	57.14
I	14.28	*V*	71.43
II	28.57	*VI*	85.71
III	42.85		

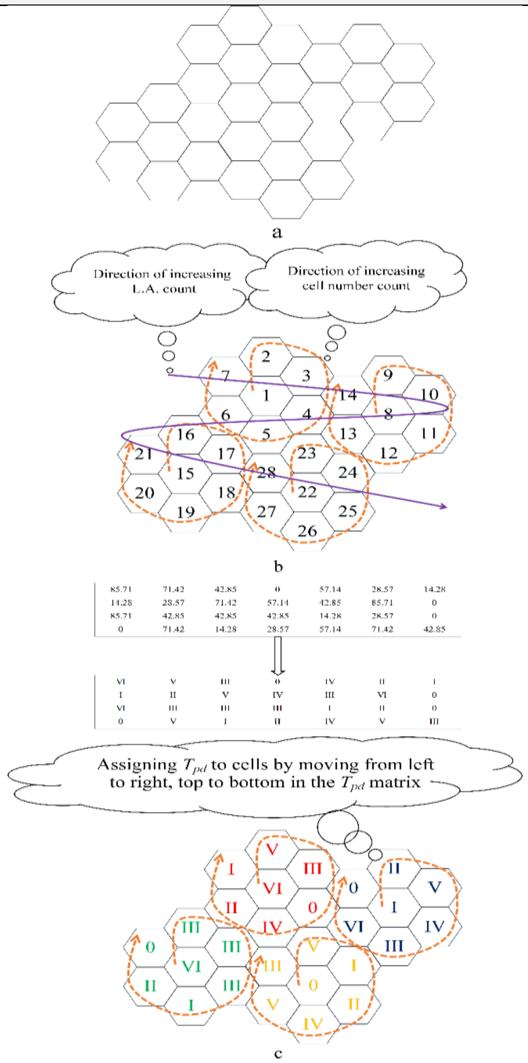


Fig. 4. Steps followed to represent a network diagram with percentile dwell time distribution.

The results are represented below:

a) For T_{d_max} = 50 (High Mobility Factor):

The dwell time distribution is as follows:

31	24	17	9	18	13	10
20	22	40	37	31	46	15
46	24	24	24	10	14	5
1	39	2	8	37	39	29

The percentile dwell time for each cell is

85.71	71.42	42.85	0	57.14	28.57	14.28
14.28	28.57	71.42	57.14	42.85	85.71	0
85.7	42.85	42.85	42.85	14.28	28.57	0
0	71.42	14.28	28.57	57.14	71.42	42.85

While predicting a possible RCP, the steps as mentioned in Table 3 are illustrated for this scenario as follows: Location Area 3 (Green colour coded) is chosen in the beginning. A user who moves from LA 3 to the neighbouring LA can move to either LA 1 (Red colour coded) or LA 4 (yellow colour coded) because these LA 1 & LA 4 share their boundaries with LA 3. The smallest T_{pd} possible in LA 3 that shares the one of most diverse boundary is cell 18, which is made a Reporting Cell. The user may move to cell 28, or 27 both of which belong to LA 4. Since T_{pd} (cell 28) < T_{pd} (cell 27), hence user is more likely to move to cell 28 than to 27. Thus, the next RC is cell 28.

Here onwards the user may change his current LA when he moves to cell 17 or 5 (cells 23, 22, 27 are ignored because they belong to the same LA, hence no LU needs to be triggered even if the user moves to those cells.) Since cell 17 would lead to a ping-pong effect, hence cell 5 is chosen as the next RC. From cell 5, the user may move to cell 6, 1, 4 or 23, out of which cell 23 shall lead to ping-pong and cell 4 has the least T_{pd} amongst cells 6, 1, 4. Hence cell 4 is the next RC. Finally, from cell 4 the user may move to cell 1,3,14 or 13. Cell 14 is chosen as the next RC. The above illustrated RCP configuration is represented in Fig. 5.

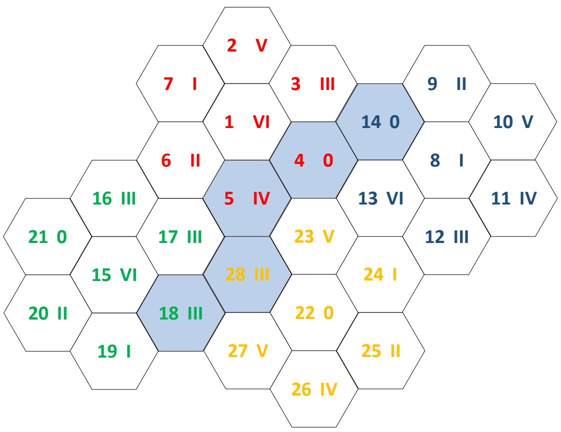


Fig. 5. RCP for T_{d_max}=50.

b) For T_{d_max}= 100 (Intermediate Mobility Factor):

The dwell time distribution is as follows:

69	65	21	61	78	85	59
55	68	71	46	36	84	55
43	64	24	46	67	26	87
65	95	12	67	42	62	27

The percentile dwell time for each cell is

57.14	42.85	0	28.57	71.42	85.71	14.28
28.57	57.14	71.42	14.28	0	85.71	28.57
28.57	57.14	0	42.85	71.42	14.28	85.71
57.14	85.71	0	71.42	28.57	42.85	14.28

A possible RCP configuration is represented in Fig. 6.

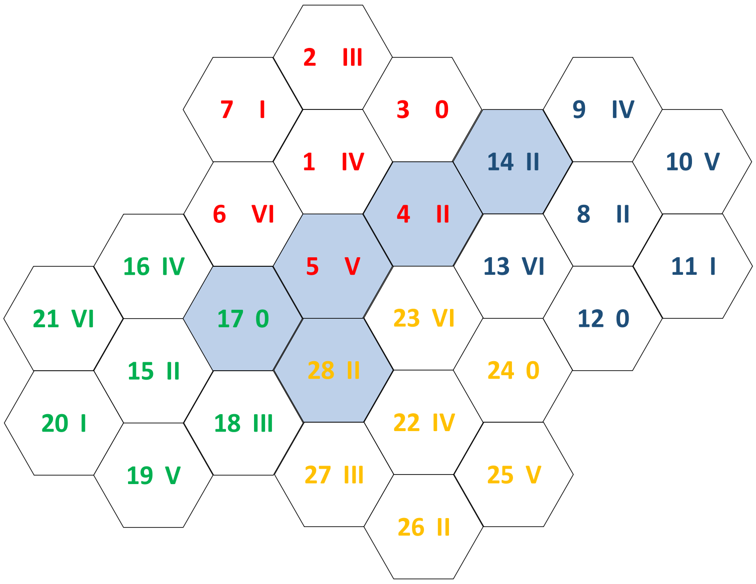


Fig. 6. RCP for T_{d_max} =100.

c) For T_{d_max}= 500 (Low Mobility Factor):

The dwell time distribution is as follows:

160	240	272	110	203	314	97
60	320	361	53	225	386	70
470	273	262	55	183	467	349
323	324	497	32	382	487	47

The percentile dwell time for each cell is

28.57	57.14	71.42	14.28	42.85	85.71	0
14.28	57.14	71.42	0	42.85	85.71	28.57
85.71	42.85	28.57	0	14.28	71.42	57.14
28.57	42.85	85.71	0	57.14	71.42	14.28

A possible RCP configuration is represented in Fig. 7.

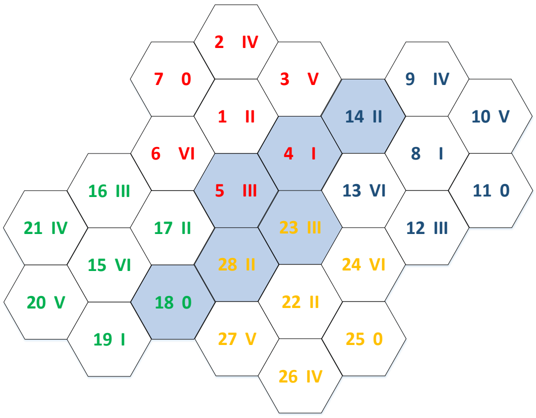


Fig. 7. RCP for Td_{max}=500.

5. Discussions

In Figs. 5-7, the shaded region represents a possible RCP configuration for each scenario. Some subtle points may be observed:

a) Although the (absolute) Dwell time distribution varies in the three cases widely (as seen from the respective dwell time distribution matrices), yet it may be noted that the percentile dwell time matrix takes fixed values only. This is because as long as the number of cells per LA remains same (7, here), the only possible values of percentile dwell time distribution are $\frac{0}{7}, \frac{1}{7}, \frac{2}{7}, \frac{3}{7}, \frac{4}{7}, \frac{5}{7}, \frac{6}{7}$. Since the absolute dwell time values for a user is already present in the network's database, it is quite easy to feed the T_{pd} table into the database, which may be scaled to any size of network. This shows that T_{pd} offers a higher level of abstraction, leading to lower computation load, hence lower mobility management cost.

b) The T_{pd} table may be updated according to the type of the network deployment. Some suggested patterns may include a 24-hour period, or scheduled duration of 8 hours thrice a day etc.

c) Here, the T_{pd} has been computed for a single user. However, for practical networks, the same kind of movement pattern may be generalised for the entire user base in a network area based on the type of locality, i.e., most users in a highway region are usually expected to move at a much faster pace than a marketplace area, so the highway region may be considered as the scenario I of our simulation set for all users within that network.

d) The RCP predicted here is not final and binding. Instead, it may be viewed as a guideline to predict RCP in general. Some compromises may need to be made in terms of assignment of the R.Cs if there is lesser need for precision, or if the resources are limited. Moreover, the RCP shape may be inclined towards providing a clear demarcation of the entire network into smaller groups of nR.Cs for the sake of symmetry.

e) The cell corresponding to 0 percentile represents that the user is the most mobile in that particular cell compared to other cells of the same LA Similarly, a cell having 85 percentile signifies that the user is least likely to move to the neighbouring LA

f) As number of cells per LA is increased, the step size of the percentile dwell time decreases, which would theoretically mean finer grained control over the user movement.

g) The traditional versus proposed location update technique has the following computational advantages.

From Table 5, it may be observed that in general, there are more no. of RCs in traditional location update technique as compared to the no. of RCs in proposed location update technique, for a given network of 28 cells. Lower number of Reporting Cells would ensure that unnecessary location update is not triggered frequently. This has been made possible only because of the inclusion of percentile dwell time factor into the location update cost equation.

Table 5. Comparison of reporting cell numbers with existing location update techniques.

Location Update Technique	Reporting Cell (Cell No.)		
	T_{d_max}= 50	T_{d_max}= 100	T_{d_max}= 500
Traditional	18,27,28,17, 5,23,4,13,14	28,18,17,6, 5,23,4,13,14	18,28,27,17,5, 6,23,4,13,14
Proposed	18,28,5,4,14	28,17,5,4,14	18,28,23,5,4,14

From Fig. 8, that the proposed technique achieves a percentage decrease of 14.28% for each of the three mobility scenarios when the ratio of number of RCs to the total number of cells in the network is concerned. This is the desired computational advantage.

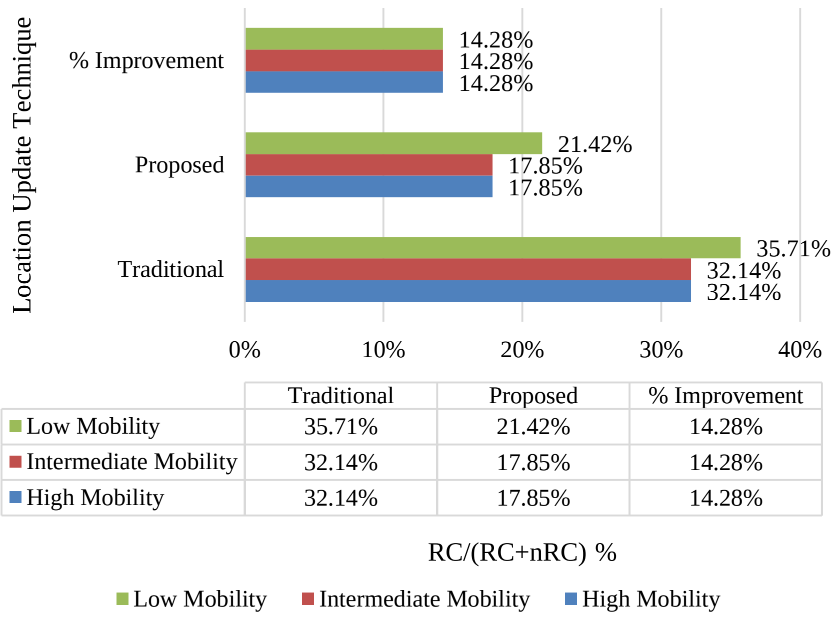


Fig. 8. Computational performance comparison with existing location update techniques.

6. Conclusion and future direction

Percentile Dwell Time Distribution was proposed as a parameter to predict Reporting Cell Planning configuration for location management in cellular networks. The proposed concept was elaborated in order to give the readers a clear understanding of how the simulations would influence the RCP in a network. Based on the proposed method, three specific scenarios of users belonging to the same size of network were presented. It was observed that the vastly differing absolute dwell time was superseded by the relatively simpler percentile dwell time.

In the future, the proposed method may be implemented to a particular user scenario with different sizes of networks. This shall give a hands-on experience on the scalability aspect of the proposed parameter. Further, simulation may be performed wherein the proposed parameter, combined with some intelligent algorithms shall be implemented to optimize the total cost of location management.

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