An Enhanced Location-Based Location Update Scheme in Mobile Cellular Networks

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ABSTRACT—In this study, we consider a location-based location update (LU) scheme. We propose an enhanced LU (ELU) scheme that can store more cells to reduce the location update cost of the LU scheme and show that the ELU scheme always outperforms the LU scheme. Our scheme can be easily implemented in actual cellular systems.

Keywords—Location update, paging, location-based location update.

I. Introduction

Effective location tracking strategy is essential to improve the utility of radio channels [1]-[6]. Due to the limited battery life and computational capacity in a mobile station (MS), one desirable feature of a location update scheme is its easy implementation in the MS. A movement-based location update scheme [4] is one of the easily implementable approaches. According to this scheme, each MS maintains a counter, whose value is compared to a movement threshold to trigger a location update. The MS performs a location update when the number of cells visited by the MS exceeds movement threshold T. In this scheme, however, the MS increases its counter value even when the MS reenters a cell previously visited, which triggers an unnecessary location update.

To overcome this deficiency, an improved movement-based location update scheme [5] and a location-based location update (LU) scheme [6] were proposed. Among them, we consider the LU scheme, which is evaluated to be superior to the improved

movement-based location update scheme.

We can improve the performance of the LU scheme considerably if we make MS have more memory space and we do not remove any cells from the list as far as memory space permits. In this study, we propose an enhanced LU (ELU) scheme that can store more cells in order to reduce the location update cost of the LU scheme. We show that the ELU scheme always outperforms the LU scheme. For the sake of conciseness, we briefly describe the LU scheme and concentrate on the new results, comparing them with those of the LU scheme in [6].

II. Enhanced Location-Based Location Update Scheme

In this section, we propose an ELU scheme which results in less location update cost than the LU scheme.

1. Location-Based Location Update Scheme

In the LU scheme [6], each MS maintains a counter C and a list of tuples (I_j, C_j), where I_j is the identifier (ID) of cell j, and C_j is the value of the counter right after the MS entered cell j most recently. The cells within the list are arranged in increasing order of the values in C_j. When the MS enters cell i, the rules to store cell i in the list and update the counter are as follows:

1. If cell i is not in the list, counter C is increased by one.
   a) If C is equal to the movement threshold T, a location update is triggered and the list is initiated with cell i.
   b) Otherwise, $C_i=C$, and pair (I_i, C_i) is added to the list.
2. If cell i is already in the list, $C=C_i$, and all cells following cell i in the list are removed from the list.

Note that the storage size required in this scheme depends on the value of T. Because the maximum required size of the list is T, the memory needed to store the list in the MS is T times the size of a tuple.

2. Motivation

Let us consider the example in Fig. 1. It assumes a threshold of T=4. When an MS reenters cell A (counter value of first visit=1) in the movement-based location update scheme, the counter value becomes 4 and a location update is performed.

In the LU scheme, when it reenters cell A, the MS doesn't perform a location update because the counter value becomes 1 (the counter value of the MS when it visited cell A previously), and cells B and C are removed from the list because the MS visited them after visiting cell A, so their corresponding counter values (C_B=2 and C_C=3) are larger than that of cell A (C_A=1). In this way, the number of location updates in the LU scheme is always less than or equal to the number of location updates in the movement-based location update scheme.

However, there is still a possibility for performance enhancement in the LU scheme. For example, consider the path where the MS reenters cell B through cells D and E, as shown in Fig. 1. In case of the LU scheme, this MS reentering cell B has 4 as a counter value and updates its location. Note, if the MS does not remove cells B and C but maintains them, when it reenters cell B (C_B=2) its counter value becomes 2 and the MS does not even update its location. In this way, if we make MS have more memory space and don't remove any cells as far as memory space permits, we can improve the performance of the LU scheme, considerably. In this study, we call our enhanced LU scheme an ELU scheme.
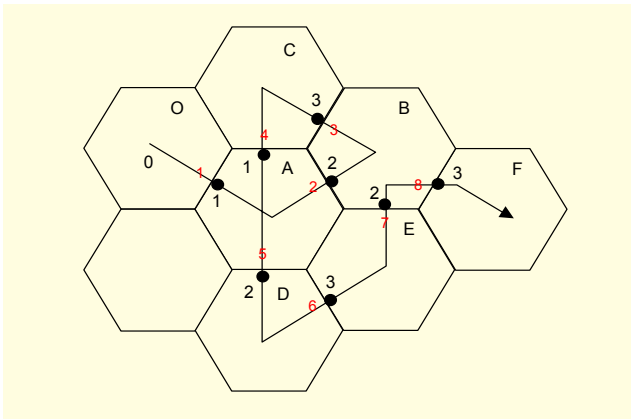

Fig. 1. An example path of an MS.

It is obvious that the ELU scheme needs more memory space than the LU scheme. However, it is not difficult economically to extend memory space, considering the very low price of memory in the market. Further, the optimal memory space of the ELU scheme is only two or three times that of the memory space of the LU scheme as will be shown in section IV. We now will describe the ELU scheme in detail.

3. Enhanced Location-Based Location Update Scheme

The ELU scheme is basically similar to the LU scheme except

for memory size, the rule of arrangement, and the rule of removal. Similar to the LU scheme, each MS maintains a counter and a list of tuples (I_j, C_j). However, the maximum required size of the list is larger than T in general, so rules of arrangement and removal of cells in the list are different from and more complicated than the LU scheme. The cells in the list are arranged in visiting order of the MS. In other words, the order of the cells in the list indicates the visiting order of the MS. When the MS enters cell i, the rules to store cell i in the list and update the counter are as follows:

1. If cell i is not in the list, counter C is increased by one.
   a) If C=T, a location update is triggered and the list is initiated with cell i;
   b) Otherwise, two cases are possible:
   If there is a vacant space in the memory, C_i=C, and pair (I_i, C_i) is added to the list;
   If there is no vacant space in the memory, cell j is removed according to the rule of removal, C_i=C, and pair (I_i, C_i) is added to the list.

   The rule of removal
   Beginning from the oldest cell, the counter value C_j of current cell j is compared with counter value C_k of cell k visited by the MS after the MS enters cell j.
   - If $C_k < C_j$, the current cell j is removed.
   - Otherwise, the oldest cell is removed.

2. If cell i is already in the list, two cases are possible.
   a) If $C_i < C$, C=C_i;
   b) Otherwise, counter C is increased by one, and two cases are possible:
   If C=T, a location update is triggered and the list is initiated with cell i;
   Otherwise, C_i=C, and pair (I_i, C_i) is modified in the list.

Note that in 2.a) cells are not removed from the list as far as
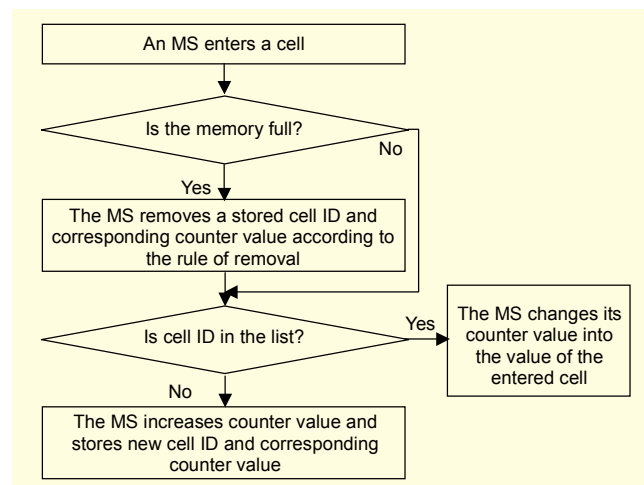

Fig. 2. Flow chart of the ELU scheme.

memory space permits, which is different from the LU scheme. Also note that, as shown in 2.b), $C_i \geq C$ is possible in this scheme since the memory can store more cells than threshold T.

III. Performance of the Enhanced Location-Based Location Update Scheme

We will show that the location update cost of the ELU scheme is less than or equal to that of the LU scheme. In this study, however, we do not consider the memory cost since it is very low and is a one-time cost. As such, it scarcely affects the superiority of the proposed scheme. So, we analyze and compare the location update cost of each scheme on radio channels, assuming that the memory cost is so low that it can be ignored.

Let us first introduce some random variables to formulate the location update cost and compare the performances analytically.

M: number of entering cells between call arrivals

N_A: number of entering new cells that are not in the list of the A scheme between call arrivals

D_A: cumulative sum of the decreased counter value of the A scheme between call arrivals whenever the MS reenters the cell that is already in the list, and further when the corresponding counter value of the reentered cell is less than the current counter value C

Table 1. Lists of the tuples and values of random variables derived from Fig. 1 for the two schemes.

Serial No.	LU scheme						ELU (2T) scheme									
	Tuples		C	L	N	D	Tuples						C	L	N	D
1	O	A	1	1	1	0	O	A					1	1	1	0
	0	1					0	1								
2	O	A	B	2	2	2	0	O	A	B				2	2	2	0
	0	1	2				0	1	2							
3	O	A	B	C	3	3	3	0	O	A	B	C		3	3	3	0
	0	1	2	3			0	1	2	3						
4	O	A	1	1	3	2	O	B	C	A			1	1	3	2
	0	1					0	2	3	1						
5	O	A	D	2	2	4	2	O	B	C	A	D		2	2	4	2
	0	1	2				0	2	3	1	2					
6	O	A	D	E	3	3	5	2	O	B	C	A	D	E	3	3	5	2
	0	1	2	3			0	2	3	1	2	3				
7	B	0	4	6	2	O	C	A	D	E	B	2	2	5	3
	0						0	3	1	2	3	2				
8	B	F	1	5	7	2	O	C	A	D	E	B	F	3	3	6	3
	0	1					0	3	1	2	3	2	3				

L_A: N_A - D_A

Then, we can see the following property.

Property. $N_{LU} \geq N_{ELU}$, $D_{LU} \leq D_{ELU}$, and $L_{LU} \geq L_{ELU}$ for every cell visited by the MS between call arrivals.

Let us examine the above random variables for Fig. 1. Table 1 represents values of random variables from cell A through cell F in Fig. 1. ELU (A) indicates the ELU scheme that can store the maximum of A cells. In this example, the value of random variable M is the same as the serial number. We also can obtain the following location update costs between call arrivals:

$$C_U^{LU} = U \sum_{i=1}^{\infty} i \sum_{j=id}^{\infty} \alpha(j) \sum_{k=id}^{(i+1)d-1} \Pr[L_{LU} = k \mid M = j],$$

$$C_U^{ELU} = U \sum_{i=1}^{\infty} i \sum_{j=id}^{\infty} \alpha(j) \sum_{k=id}^{(i+1)d-1} \Pr[L_{ELU} = k \mid M = j],$$

where U is the unit location update cost required for one location update and $\alpha(j)$ is the probability that an MS enters j cells between call arrivals. In the above equations, we obtain the value of $\Pr[L \mid M]$ using computer simulations. We decided to use computer simulations because this calculation is so complicated that it is difficult to obtain results. Finally, we can obtain the following corollary.

Corollary. For every cell visited by the MS between call arrivals, the number of location updates of the ELU scheme is less than or equal to that of the LU scheme. That is,

$$C_U^{ELU} = U \sum_{i=1}^{\infty} i \sum_{j=id}^{\infty} \alpha(j) \sum_{k=id}^{(i+1)d-1} \Pr[L_{ELU} = k \mid M = j]$$

$$\leq U \sum_{i=1}^{\infty} i \sum_{j=id}^{\infty} \alpha(j) \sum_{k=id}^{(i+1)d-1} \Pr[L_{LU} = k \mid M = j] = C_U^{LU}.$$

Finally, we can obtain the following total signaling cost between call arrivals C_T for location update and paging:

$$C_T = C_U + C_P = C_U + V[1 + 3T(T-1)],$$

where C_P is the paging cost between call arrivals, V is the cost for paging a cell, and $[1+3T(T-1)]$ is the total number of cells in a location area. Note that it is assumed that all cells in the location area are paged simultaneously whenever an incoming call arrives.

IV. Numerical Results

For illustrative purposes, the hexagonal cell configuration of [4]

and [6] is assumed. The cell residence time and the incoming call arrivals are assumed to follow an exponential distribution with λ_m and a Poisson process with λ_c, respectively. It is also assumed that U=10 and V=1 [4].

Figure 3 shows the location update cost between call arrivals for two schemes for varying values of movement threshold T, given that the call-to-mobility ratio (CMR) is 0.25. The CMR is defined as λ_c/λ_m and a low CMR represents high mobility. In the figure, we can see that the update cost of the ELU scheme is always less than that of the LU scheme. Further, we can also see that ELU (2T) and ELU (3T) make little difference, so we assume from now that the ELU scheme stores a maximum of 2T cells.

Figure 4 shows the location update cost of the ELU (2T) scheme for different CMR values. In the figure, we can see that the ELU scheme achieves a significant cost reduction compared to the LU, especially when the CMR is low. It is also shown that the update cost decreases as the threshold increases, but the reduction ratio (LU-ELU)/LU increases as the threshold increases.

Figure 5 shows the location update cost, paging cost, and total signaling cost of the two schemes for varying values of movement threshold T, given CMR=0.1. In the figure, we can see that both of the schemes have the optimal total cost when threshold T=3, and around a 3.3% reduction in total cost (and around a 5.8% reduction in registration cost) is achieved in the proposed scheme. It is expected that a more significant cost reduction can be achieved in the proposed scheme as the CMR decreases.
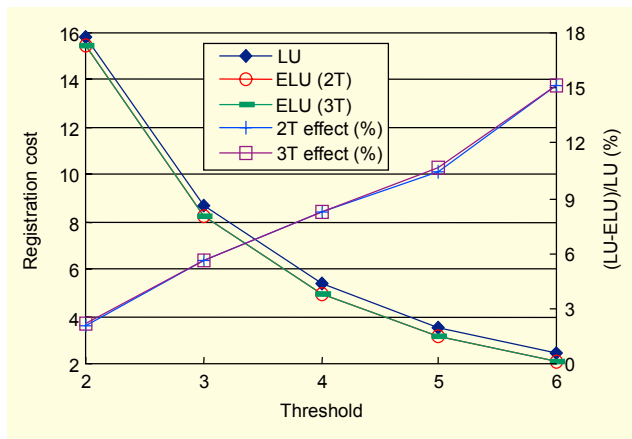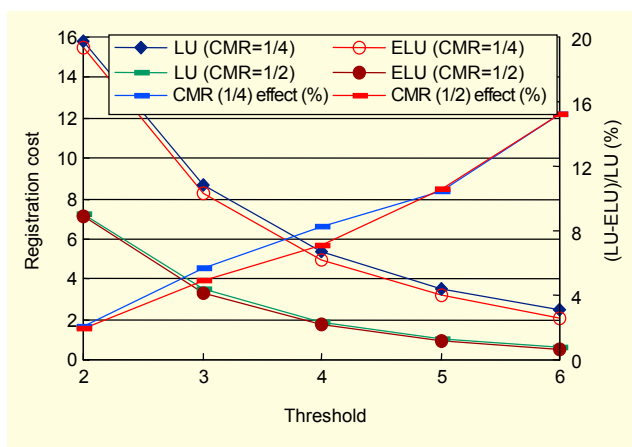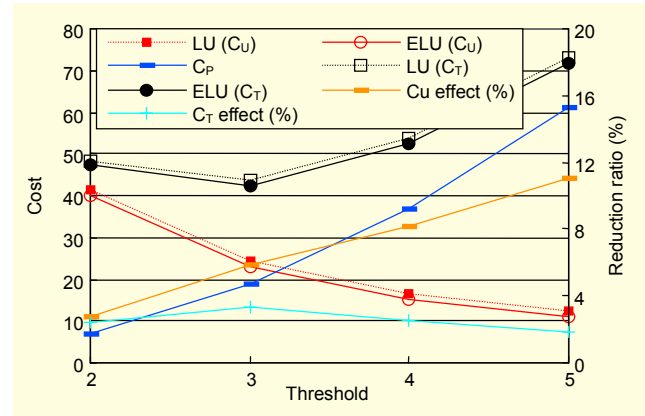

Fig. 5. Total cost for the two schemes (CMR=0.1).

V. Conclusion

In this study, a location-based location update (LU) scheme [6] was considered. An enhanced version of the LU scheme was proposed that can store more cells to reduce the location update cost of the LU scheme. A considerable reduction in location update cost was achieved in our proposed scheme. Our scheme can be easily implemented in actual cellular systems.

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Fig. 3. Location update cost for the two schemes (CMR=0.25).

Fig. 4. Location update cost of the ELU scheme.