J. King Saud Univ., Vol. 15, *Eng. Sci.* (2), pp. 249-260, Riyadh (1423/2003)

Channel Borrowing with Minimal Locking (CBML) for Efficient Spectrum Utilization in Cellular Systems

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(Received 19 September, 2001; accepted for publication 02 April, 2002)

Abstract. In this research work, a new channel assignment technique that takes into consideration the location of the user that could be found anywhere in the cellular area is developed, simulated and compared with some bench mark techniques. The scheme is applied on 49 hexagonal cells. A design of a locking parameter in case of borrowed channels is made which acts as an indicator to locking or unlocking of the identical channels in co-channel cells. This scheme has maintained the traffic quality of the borrowed channel, without reducing its power. As a result, this scheme is found superior in performance over all the conventional channel assignment schemes, like the Fixed Channel Assignment (FCA) and the Borrowing Channel Assignment (BCA) schemes, in the sense of utilizing the available spectrum efficiently and thus increasing the capacity of the cellular system.

Introduction

The number of users of wireless communication systems is drastically growing. This applies to the variety and nature of services offered by operators of these systems. However, the limited radio frequency spectrum allocated to these systems puts an upper bound to the overall system capacity. As such, extensive research has been dedicated to the development of techniques that deal indirectly with channel capacity enhancement. These techniques depend on the nature of services and its domain. For example, frequency reuse techniques or channel assignment techniques, Fixed Channel Assignment (FCA), Dynamic Channel Assignment (DCA) emanated in the seventies as an integral part of the mobile communication systems.

In addition, sectorization could be used to indirectly enhance the capacity of the cellular system by reducing the co-channel interference that usually exists in nonsectored systems. Multibeam smart antennas play similar roles to the improvement of spectrum utilization and consequently to the up gradation of the system capacity.

The sectorization and multibeam antenna approaches will not be investigated in this research work. Emphasis is centered on the development of conventional channel assignment algorithms to upgrade the spectrum reuse efficiency of existing GSM systems.

Different types of traffic require different propagation channel characteristics. To effectively utilize the assigned limited spectrum resource, various channel allocation schemes have been developed for voice transmission [1 – 5].

Bandwidth sharing schemes between voice and video channels is proposed in [6]. In common, the schemes developed so far increased the system capacity noticeably.

Fixed and dynamic channel assignment schemes are the basic schemes in determining the Grade Of Service (GOS), which is a measure of the ability of a user to access a trunked system (a system that allows a large number of users to share the relatively small number of channels in a cell by providing access to each user on demand) during the busiest hour.

Versions of the FCA Technique are presented in [7-9] and some versions of DCA techniques are presented in [4], [8] and [9].

In FCA, a certain number of channels were allocated to each cell on fixed basis. If all the channels in a certain cell are busy, then any new call attempt in that particular cell is blocked. In DCA, all channels are kept in a central pool and they are offered to the users in a cellular area on demand, taking the probability of co-channel interference into account.

A Hybrid Channel Assignment (HCA) scheme is presented in [4], in which a division is made between static and dynamic channels, taking the advantages and merits of each scheme separately. It was found that dynamic DCA channels have a good performance at low traffic conditions and the FCA channels have a good performance at high traffic conditions.

A borrowing scheme presented by [10] is a flexible version of FCA. In such a Borrowing Channel Assignment (BCA) scheme if all channels in one cell are busy, then a new call attempt within that cell could be served by a borrowed channel from a nearby cell, if available. In all conditions of borrowing in this scheme, there is a necessity of locking two identical channels if both are free to prevent co-channel interference.

In this paper, we propose a new borrowing scheme; we call it Channel Borrowing with Minimal Locking (CBML). The merits of this scheme emanate from it’s ability to deal with users of previously estimated locations which exist in the cellular coverage area. In the CBML scheme, a channel could be lent with at most two locks. The performance of this scheme, as compared with the conventional FCA, DCA and HCA schemes is superior especially at high traffic loads.

The CBML Scheme

A. Locking parameter and channel borrowing

Figure 1 shows the layout of the hypothetical cellular communication coverage area. This basic hexagonal layout with base stations using omni-directional antennas are adopted, just for convenience of presentation and explanation. Clusters of frequency reuse pattern size of 7 is also used for explanation purposes.

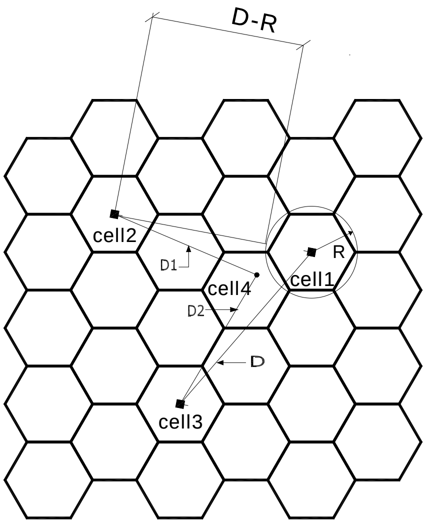

Fig. 1. Channel locking - determining distances in the CBML scheme.

The CBML scheme is based on the awareness of the base station about the location of the user. A high service priority is given to users close to the serving base station and relatively lower priorities are given to further users. If all channels of the host base station are occupied and a new call arrives, the CBML borrowing is employed.

Let R be the radius of a cell, D the reuse distance which is usually defined as the distance between the centers of cells that are co-channel interference limited. Denote the ratio of D to R as Q, i.e,

$$Q = D / R \tag{1}$$

Q is known in literature as the co-channel reduction factor [1]. If Q is maintained high, the co-channel interference decreases. It is actually a measure of co-channel interference suppression due to propagation loss.

D can also be determined in terms of the cluster size, K:

$$D = \sqrt{3K}R \qquad (2)$$

Where,

$$K = i^2 + ij + j^2 \qquad (3)$$

i,j are integers that determine the reuse pattern and consequently identify co-channel cells. From equations (1) and (2), one can determine the locking parameter, Lp:

$$Lp = D - R = R(Q-1)$$

$$Lp = R(\sqrt{3K} - 1) \qquad (4)$$

Table 1 shows typical values to Lp for cluster sizes 3,7 and 12.

Table 1. Locking parameter in terms of R

Cluster Size (K)	(Q)	(L_p)
3	3	2R
7	4.6	3.6R
12	6	5R

The locking parameters will be used as an indicator to the probability of a channel locking due to co-channel interference where the CBML algorithm is applied. Now, we illustrate how the estimate of the location of the user can be incorporated with the locking parameter, Lp, to determine the possibility of locking of involved co-channels. Cells are assigned fixed numbers of channels, no distinction between these channels from the base station point of view, i.e, all channels of a cell can be used by that cell if necessary or some can be borrowed by adjacent cells if a vacancy is available. In Fig. 1, let cell1, cell2 and cell3 be co-channel cells that fulfill the condition of the reuse distance. Let a channel x be borrowed by a user in the adjacent cell to cell1 (cell4 in Fig. 1). Let D1 and D2 represent the distance between that user, and cell2 and cell3 respectively. The borrowing of a channel with or without locking depends on the following criteria:

1. If D1 and D2 < Lp, both co-channels in Cell2 and Cell3 will be locked.
2. If D1 < Lp and D2 > Lp, the channel in cell2 is locked, while that in cell3 is kept free.
3. If D1 > Lp and D2 < Lp, the co-channel in cell3 is locked , while that in cell2 is kept free.

4. If D1 and D2 > Lp, both co-channels in cell2 and cell3 will be free and could be used by their host cells.

Three frequency reuse patterns are studied, namely, K = 3, 7 and 12. For clusters of K = 3 and K = 7, we restrict the borrowing to be from these co-channels of the first tier to maintain acceptable GOS value without any necessity to vary the power level. Thus, from the geometry of the architecture of Fig. 2.a, one can deduce the maximum distance between the position of a user and a possible donor cell.

$$d_{3,7} = R + 2R\cos(30°) \quad (5)$$

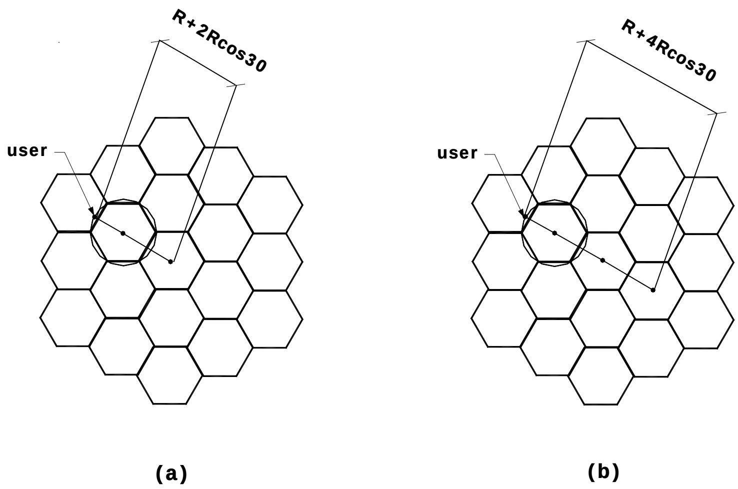

Fig. 2. Maximum distances to donor cells: (a) k = 3, 7 (b) k = 12.

For a cluster pattern of $K = 12$, the groups of channels are almost distributed over the first and second tiers. Therefore, it is possible to benefit more distant users without risking the GOS level. The maximum possible distance between a user and a possible donor cell can be calculated from the geometry of Fig. 2.b.

$$d_{12} = R + 4R\cos(30°) \quad (6)$$

The Simulation Process

The simulation processes we do in this paper are based on the following essential hypothesis:

a) We use the cellular architecture shown in Fig. 3 to accomplish full communication coverage of the area of interest. This coverage area is divided into 49 cells with a cell radius R that satisfies the toll traffic quality and the co-channel reuse distance constraints. Each cell is assigned a global number, in the range 1 to 49. The location of each base station, $P_b(k)$, of the 49 cells adopted in the simulation is identified by its (x , y) co-ordinates, i.e, (x(k) , y(k)) gives the location of the kth base station in the orthogonal xy-plane (figure 3); k = 1,2, … , 49, in terms of arbitrarily chosen R. Each pair of cell location co-ordinates is computed and considered as an element of a 2 – D array that usually reflects the cellular architecture under consideration. For example, from the plane geometry of Fig.3, the co-ordinate pair (x(1), y(1)) representing the location of cell1 is (0,0) and that for cell4 is (4.5R, 2.598R), since x(4) = $(\frac{\sqrt{3}}{2} + \sqrt{3} + \sqrt{3} + \frac{\sqrt{3}}{2})\,R\cos 30^\circ = 4.5\,R$ and $y(4) = (\frac{\sqrt{3}}{2} + \sqrt{3} + \sqrt{3} + \frac{\sqrt{3}}{2})\,R\sin 30^\circ = 2.59\,R$.

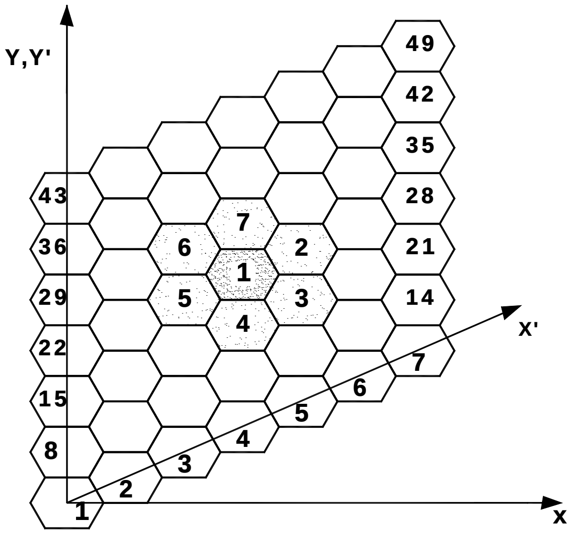

Fig. 3. The cellular layout used in simulation.

b) Each cell is assigned a local number in the range 1 to K; K is the cluster size, for example, for a cluster size of 7 all cells are arranged to take numbers in the range 1 to 7.

c) 41,17 and 10 voice channels for cluster patterns 3, 7 and 12 respectively are allocated to each cell. This is based on the basic 125 channels provided by a conventional GSM mobile communication system.

d) For each cluster pattern, co-channel cells to each cell are identified and arranged in arrays and labeled for further processing.

e) A base load, A, that corresponds to a 2% call blocking is offered to each cell; according to equation (7).

$$A = \frac{Q_i T}{60} \quad \text{Erlangs} \tag{7}$$

Where, Q_i is the maximum number of channels per hour per cell, T is the average call holding time. These offered base loads equal 31.9, 10.7 and 5.08 Erlangs for cluster patterns 3,7 and 12 respectively [1].

The following summarizes the main steps of the simulation processes for all cluster patterns:

Step 1: A base traffic that corresponds to a GOS of 2% blocking is offered to each cell. This, effectively, makes up a corresponding Poisson distribution "call attempt" for all cells.

Step 2: The base load of the whole system incremented in steps of 1%, i.e, a corresponding increase in the traffic intensity, n, is offered to the whole system and the average number of blocked calls is computed.
This is done through 10 seconds repeated trials over a time span of 3 minutes (average call duration).

Step 3: The users are assigned random positions uniformly distributed over the cellular coverage area, i.e, for each call arrival there would be a corresponding user location designated by $P_c(j)$ and determined by his (x , y) co-ordinates, for example, (x (j) , y(j)) represents the location of the jth user.

Step 4: Use equation (8) to calculate the distance between the kth base station and the jth user (see Fig. 3).

$$R_{jk} = \sqrt{(x(j) - x(k))^2 + (y(j) - y(k))^2} \tag{8}$$

Practically, a Global Positioning system (GPS) unit that could be incorporated within the mobile unit is sufficient for the base station to identify the location of the mobile unit.

Step 5: Identify and ignore all cells that satisfy $R_{jk} > d_{3,7}$ or d_{12} as given in equations 5 and 6. This means that these cells cannot be used as donors in the CBML scheme. Similarly, identify all cells that satisfy $R_{jk} < d_{3,7}$ or d_{12} and consider them as nominal donor cells.

Step 6: Evaluate the co-channel cells corresponding to the nominated donor cells obtained in step 5 and use the locking parameter, Lp, value to determine if the corresponding co-channels to each user is to be locked (if available) or not.

Step 7: Search and Sort the available channels that satisfy the minimum locking concept and the closest to each user and assign these channels to the corresponding user, other wise, the call is blocked.
Counters are set to count the number of calls representing the differential load intensity and the number of blocked calls.

Step 8: Evaluate the average percentage of call blocking corresponding to each 1% base load increment until a 100% traffic intensity is reached.

Simulation Results

Figures 4, 5 and 6 show a percentage increase in call blocking versus a one-percent increase in traffic for which the CBML along with FCA and BCA schemes, abbreviated N, F and B respectively, are applied on three cluster sizes 3,7 and 12.

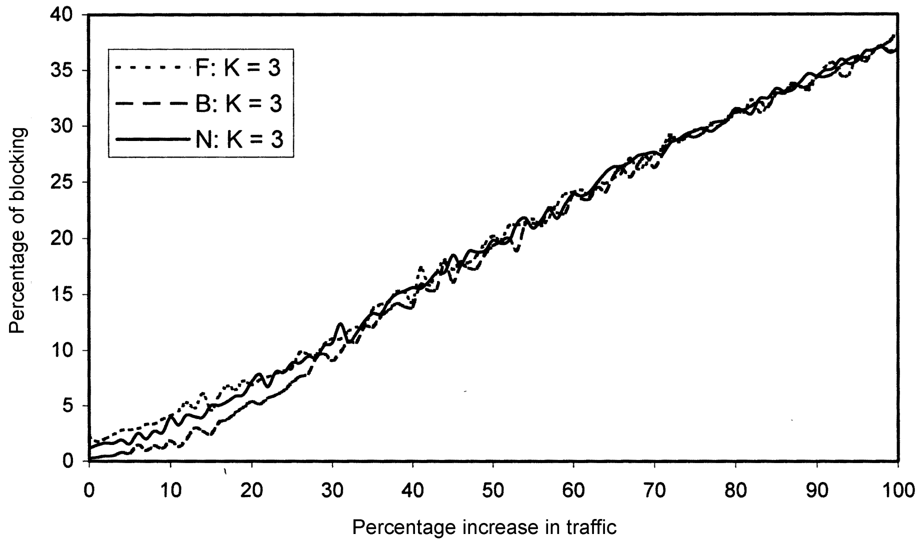

Fig. 4. Performance of schemes for k = 3.

Figure 4, shows a hundred percent increase in load offered to cluster size 3, and shows that, the CBML channel assignment scheme performance lies between the fixed scheme and the borrowing scheme in the region below 30% of the offered load. After that, it acts like the FCA scheme as given in [7] and [9]. No substantial improvement in the performance of the CBML scheme over the FCA is observed for this pattern size. This is attributed to the limitations of channel groups of this small cluster size.

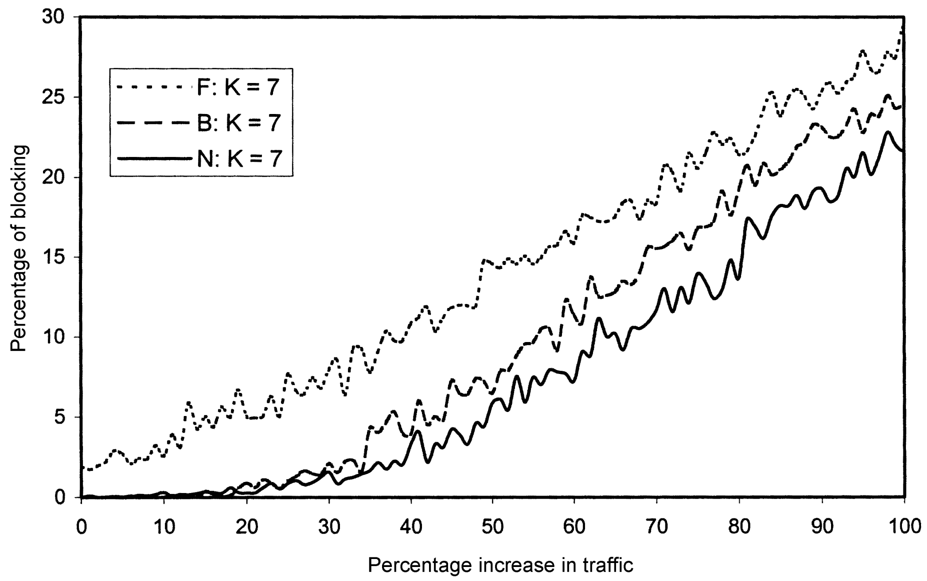

Fig. 5. Performance of schemes for k = 7.

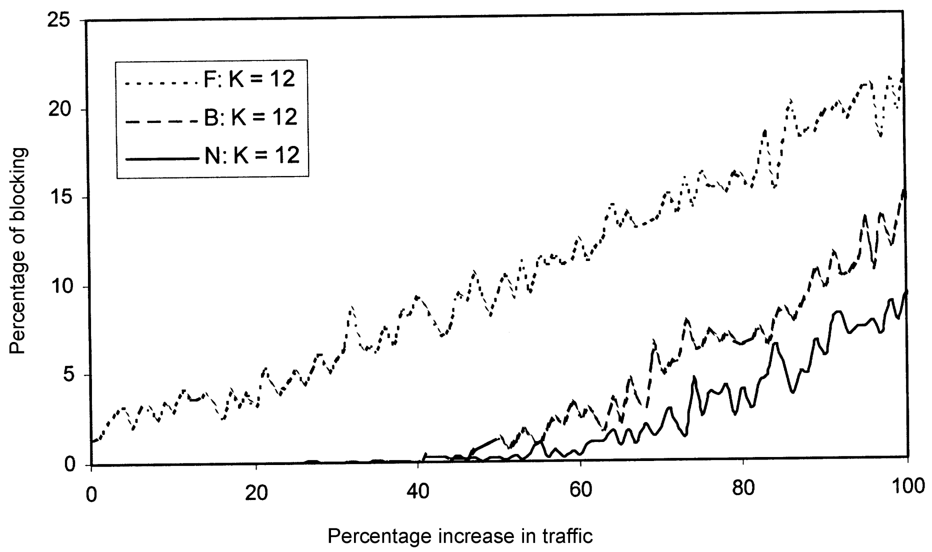

Fig. 6. Performance of schemes for k = 12.

Figure 5 shows the performances of schemes for a cluster size 7. In this organization, more channel groups are created and the influence of limited channel groups, which caused the CBML scheme to act worse than the borrowing scheme, in the cluster pattern 3, is reduced. One can deduce that about 12% relative improvement in the CBML performance is achieved over the BCA scheme and about 26% relative improvement over the FCA scheme, assuming a 100% increase in traffic loads.

Figure 6, shows the performance for all cell clusters of size 12. In this case the problem of limited channels is reduced further, and the CBML scheme showed its superiority over the FCA and the BCA. As obvious the BCA blocking probability started above 40% increase in load, while the CBML scheme blocking probability started above 50% increase in load. About 37% relative improvement in the CBML performance is achieved over that of the BCA scheme and about 58% relative improvement over that of the FCA scheme assuming a 100% increase in traffic loads.

Table 2 shows the blocking probabilities, obtained from the simulation for FCA, BCA and the CBML schemes at 100% increase in load offered to the given cluster sizes.

Table 2. Blocking probability for FCA, BCA and New CA at 100% increase in traffic.

Cluster size (K)	Blocking at 100% increase in load		
	FCA	**BCA**	**CBML CA**
3	36.89	38.25	36.78
7	29.38	24.68	21.71
12	22.13	14.91	9.34

The Performance of the CBML channel assignment is better than all the conventional channel assignment schemes. It performs better than the DCA scheme [8] and [9] at both low and high traffic loads.

The performance of HCA scheme [4], is not even comparable to the performance of the CBML channel assignment scheme, either at low, or high traffic loads, and irrespective of the partition between static and dynamic channels.

Conclusions

A newly developed channel assignment scheme is introduced, it has been modeled simulated, and its performance is compared with the conventional existing schemes, such as, FCA, DCA, HCA and BCA. These schemes are mainly developed, for reducing the blocking probability and utilizing the available bandwidth, assigned to the cellular system efficiently.

The newly developed scheme is more realistic than all mentioned schemes, as it takes into account the location of the user that could be found anywhere in the cell area. The decision to lock a channel depends on the location of the user and the locking parameter, L_p.

In the CBML channel assignment, a channel could be borrowed without reducing its power, thus maintaining an acceptable GOS on of the borrowed channel.

Channel switching, that keeps the first nominal channels within the cell busy and channel prioritizing, that keeps the first nominal channels to serve the mother cell, and the last nominal channels to be lent to the adjacent cells, introduced by [10] can add a further improvement to the CBML channel assignment scheme.

The BCA and the CBML channel assignment schemes act as the fixed channel assignment scheme at high loads. This was noticed within the hundred percent increase in load for cluster size 3, while, for cluster sizes 7 and 12, the trend to act like FCA started to appear beyond the 100% increase of traffic loads.

In the light of integrating users location finding techniques and smart real time tracking antennas in mobile communications, it is expected that the CBML scheme will have an outstanding bandwidth utilization efficiency as compared to other schemes. As such it is recommend to investigate the performance and efficiency of this CBML scheme after being integrated with such smart cellular systems.

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استعارة القنوات بالحد الأدنى من الإغلاق لاستخدام كفء للنطاق الترددي في الأنظمة الخلوية

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ملخص البحث. تم في هذا البحث تطوير ومحاكاة طريقة "استعارة القنوات بالحد الأدنى من الإغلاق" لتخصيص قنوات الاتصال لمستخدِم أنظمة الاتصالات الخلوية والتي تأخذ بعين الاعتبار مكان وجود المستخدِم حيثما كان ضمن مساحة التغطية الجغرافية لهذه الأنظمة، كما جرى مقارنة أداء هذه الطريقة مع أداء بعض الطرق ذات المرجعية بهذا الخصوص.

تم تطبيق هذه الطريقة على منطقة تغطية مقسمة إلى ٤٩ خلية سداسية الشكل حيث تم تطوير وحساب معاملٍ أو مؤشرٍ للإغلاق ليكون المقرِّر لإغلاق أو عدم إغلاق القنوات المتشابهة والمحدَّدة بالتشويش المتبادَل في حالة الإعارة مع الأخذ بالاعتبار المحافظة على مستوى الجودة للانسياب المروري دون تخفيض القدرة .

تدل النتائج المستخلصة من مقارنة "طريقة استعارة القنوات بالحد الأدنى من الإغلاق" مع أداء الطرق الأخرى ذات المرجعية مثل طريقة "الطريقة الثابتة للتخصيص" أن تحسنا نسبيا طرأ على الكفاءة في استخدام النطاق الترددي المتوافر وبالتالي إلى زيادة سعة النقل للأنظمة الخلوية.