Power Control in Dynamic Channel Assignment Algorithms For Cellular Systems

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Abstract - ***Many Dynamic Channel Assignment algorithms (DCA) were proposed in the literature in order to improve cellular systems performance. Many of them did not consider the joint application of power control. Even when power control was considered, it is hard to compare algorithms since each of them was evaluated under a different scenario. In this paper, several important DCA algorithms are compared under the same scenarios and the effect of power control is analyzed.***

1. Introduction

DCA is an adaptive resource allocation method that can improve cellular system performance [1-11]. In DCA, communication channels are not previously allocated to base stations as in the standard fixed channel assignment (FCA); channels can be used anywhere and are dynamically allocated based on the local traffic situation and local interference measurements.

The main goals of DCA are: adaptability to time or space traffic load variations; autonomous frequency planning and capacity gain over FCA [1,2,9,10].

Many different DCA algorithms were proposed in the literature; however, many of these algorithms did not consider the application of power control [4,8].

It is also hard to compare them because they were evaluated under different scenarios and conditions. In addition, even when power control was considered, the power control scheme used was different from one report to another [1,2,9]. In order to better compare DCA algorithms, they should be evaluated under the same power control scheme and scenario [1].

This article evaluates the performance of the main DCA algorithms under the same power control scheme and scenario.

2. Interference Adaptive DCA Algorithms

In present cellular systems, channels (resources) are fixedly distributed among cells in the system. The number of channels in each cell depends on the offered traffic predicted by the corresponding service area. This way of assigning channels to cells is usually called Fixed Channel Assignment (FCA) in the literature. Some FCA drawbacks were identified: difficulty in handling time-variant traffic, lower trunking efficiency and need for frequency planning. In early cellular systems, usually composed of cells covering large areas, traffic load did not vary much; however, with the employment of microcells, the forecasted traffic load is expected to vary much more bringing a problem to fixed resource distribution methods. In addition, the hard task of frequency planning will become even harder when using micro and picocells [2,5,6,8,10].

DCA has been proposed in the literature in order to mitigate the above related problems. Initially, DCA was a technique to increase the trunking efficiency of cellular systems by allowing the borrowing of radio channels among cells. The increased trunking efficiency allowed higher capacity since each cell could hold more calls simultaneously. This type of DCA was called Traffic Adaptive-DCA (TA-DCA) since the system could rearrange the channels among the cells based on the instantaneous traffic condition. TA-DCA was widely studied and many papers reported several different algorithms. In spite of the differences among the algorithms, most of them resulted 40%-60% of additional capacity over the standard FCA [3,8]. However, TA-DCA algorithms have some drawbacks: need for complex and centralized coordination and poor performance in high traffic conditions [2-4]. In addition, TA-DCA algorithms still require frequency planning.

In order to allow a completely decentralized system and to avoid frequency planning, a new type of DCA was suggested; instead of adapting just to the traffic conditions, this new type of DCA adapts to local interference conditions. This type of DCA is called Interference-Adaptive DCA (IA-DCA). This type of DCA has also been studied for some years now and these studies have shown that IA-DCA can adapt to changes in traffic and avoid frequency planning in a completely distributed manner without the need for centralized coordination [2,5,6]. This adaptability brings additional trunking efficiency and allows shorter reuse distances [1,2,5-10]. The additional trunking efficiency can improve system availability or system capacity.

IA-DCA algorithms generally work in the following way: once a user needs a channel to establish a communication, its mobile unit and the corresponding base station sense the interference present on all the channels, in the forward and reverse path, and rank them based on the channel selection policy. Based on these measurements, base station and mobile unit decide which channel to use.

Once a call is established, mobile unit and base station constantly monitor the quality (SIR) of the channel in use. If the quality drops below a certain threshold (minimum SIR), the mobile unit and base station try to switch channels. This is usually called intracell hand-off since the mobile unit stays connected to the same base station (switching of base stations is not considered here). If the mobile unit or base station can not find a new channel with enough quality, the call is interrupted [6].

FCA and TA-DCA algorithms allocate channels based on the worst-case assumption that mobile terminals can be located in the vicinity of the cell. IA-DCA algorithms do not consider this assumption. In IA-DCA algorithms, the same channel can be used in shorter reuse distances depending on the SIR conditions [1,7]. In some cases, the same channel can be reused in neighbor cells.

IA-DCA algorithms can be classified as follows: (this classification is a slight modification in the classification suggested by Whitehead [1].)

Admission Policy: calls can be accepted in a Timid, Polite or Aggressive way. When accepting calls in a Timid way, new calls are only assigned to channels if they do not interfere with on-going calls in that channel. In the Polite way, new calls are accepted provided interfered on-going calls find a new channel. In the Aggressive way, new calls are accepted regardless of the interference it generates in other calls. This article only considers the Aggressive admission policy, since the Timid and Polite admission policies do not allow a distributed implementation, requiring some central coordination.

Channel Selection Policy: decides which of the available channels will be allocated for a call. In this article we consider the following channel selection policies:

· RANDOM: searches the list of available channels starting from a random point and selects the first channel with SIR higher than the Acceptance SIR.

· BEST_QUALITY (QUAL): selects the channel with the highest SIR, provided it is higher than the Acceptance SIR.

· BEST_PRICE (PRICE): selects the channel with the lowest SIR, provided it is higher than the minimum SIR.

· PRIORITY: selects the highest scoring channel given a predefined cost function, provided it is higher than the minimum SIR.

Among the several priority functions that can be used in the Priority channel selection policy, this article will consider the two most promising: "Channel Segregation" (CHANSG) and "Autonomous Reuse-Partitioning" (RUP).

In CHANSG, each Base Station keeps and updates a priority table. Each channel priority is increased or decreased based on past successful allocations and measurements [5,11].

In RUP, channels are allocated based on the "reuse" pattern. This means that mobiles close to the station can reuse more a channel than mobiles far from the station. Base Stations use a priority function based on the distance separating the mobile and its base station [2,5,7]. The RUP algorithm considered here is the variation suggested by [7].

Channel Use Policy: once a channel is selected, it decides how the call is going to use the channel.

· Fixed Transmitted Power: the transmitted power from mobiles and base station will be fixed in the highest value.

· Power Control: the transmitted powers from mobiles and base stations are regulated based on the channel condition.

The power control can be applied in different ways: based on the received signal or based on the present channel SIR [1,9]. In this article, we consider the received signal power control, which regulates the power in order to keep the received signal constant in a fixed value. This type of power control was studied by several other articles [5, 6 and 8].

The analysis and results presented here can be applied to an ideal multicarrier switching FDMA/TDMA system, considering each time-slot as a separate channel.

3. Simulated Scenario

The simulated cellular system had 196 hexagonal cells with 70 channels. The edges of the system were connected to the opposite edge in order to avoid the "edge-effect" [1]. The base stations were omnidirectional and uniformly spaced by 2.1km.

The propagation model considered that the average received signal decreases with the fourth power of the distance (d^{-4}) with an additional lognormal fading component with 6dB standard deviation.

The system was always interference-limited. Users were always connected to the base station providing the strongest signal.

The generated traffic was Poisson distributed and uniformly spread over the service area. Calls had an average of 100s. Mobility was not considered. Statistics were collected after the steady state was reached.

The calls were accepted if the estimated SIR on the channel was higher than the Acceptance-SIR threshold. Intracell hand-offs were triggered whenever the SIR on the channels dropped below the minimum SIR (15dB).

FCA was also simulated under these conditions. This means that, due to lognormal fading, the SIR of a call may drop due to excessive unforeseen interference, causing intracell hand-offs. FCA also checks whether the SIR in the candidate channel is above the Acceptance SIR. Thus, even if channels are available, a call can be blocked if its SIR is not high enough. FCA was configured with 7-cell cluster size.

FCA and DCA algorithms had their Acceptance-SIR adjusted to provide equalized performance regarding stability and quality. Algorithms were considered equalized when they resulted in low interruption probability (~2%-3%) and the same 10th percentile SIR level among them. This means that 90% of the calls have average SIR above this SIR level.

The simulation program was designed specially for resource allocation simulations and was programmed in standard C code. Each call has its SIR tracked during its duration, and the interference conditions were reevaluated in each event.

4. Performance Evaluation

The evaluation statistics that were gathered from the simulations are:

· new call blocking probability;
· interruption (call drop) probability;
· interference probability;
· call quality (SIR level)

In order to evaluate the effect of power control, all algorithms were evaluated primarily without power control. Them power control was applied and its effect was analyzed.

5. Fixed Power Control

In the results presented below, the simulations considered that all base stations and mobile units were transmitting at the maximum power level.

The Acceptance-SIR in each algorithm was adjusted to provide equalized stability and call quality. Regarding stability, the Acceptance-SIR threshold resulted an interruption probability close to 2% and calls quality of 21dB SIR at the operation point. The Acceptance-SIR levels were adjusted in different levels for each algorithm: FCA: 17dB; QUAL: 16dB; PRICE, RUP: 20dB; CHANSG, RANDOM: 19dB.

Figure 1 shows the blocking probability obtained.

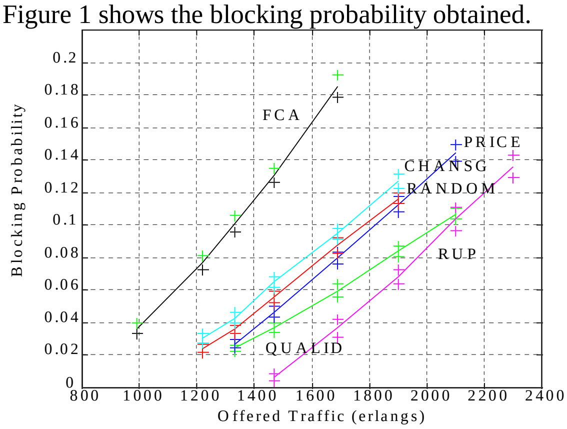

figure 1

From the above figure, if we consider all algorithms operating at 4% blocking probability, DCA algorithms showed additional capacity when compared to FCA:

QUAL:	49%
PRICE:	41%
RANDOM:	34%
CHANSG:	29%
RUP:	70%

The additional capacity is not as high as found in evaluations from other articles [1,3,4]. The lower DCA capacity gain found is justified by the equalization criteria. If we do not consider the equalization, capacity gains can be as high as 150% over FCA.

The fact that QUAL shows better performance than PRICE might seem strange. This is justified by the different Acceptance-SIR used in QUAL and PRICE. Since QUAL always allocates the channel with the best SIR, it has good performance regarding call quality and interruption probability. Thus, the Acceptance-SIR does not need to be much higher than the minimum SIR. Since, PRICE prefers to allocate channels with the worst SIR possible, it shows poor performance regarding interruption probability and call quality. Thus, it was necessary to increase the Acceptance-SIR to 20dB. If PRICE and QUAL were compared under the same Acceptance-SIR, PRICE would result in a much higher capacity gain than QUAL.

Since RUP provides higher priority to channels offering the best reuse based on the mobile location relative to the base station, its decisions could generate more "compact" allocations than other algorithms [2,5,7]. A channel is called "compacted" whenever it is used with users as close as possible to each other [3], allowing higher system capacity.

CHANSG is an algorithm that provides higher priority to successful past allocations. Since the priority function does not consider how compact the channel was allocated, the final priority table reflects a system with average compact channels.

The histograms shown in figure 2 and 3 help in the comparison among all the algorithms. Figure 2 shows the Average SIR histograms from all algorithms at the operation point confirming that all algorithms were equalized at the same 10th percentile SIR level. Figure 3 shows the Allocated SIR histograms, showing that QUAL could allocate channels with lower SIR, allowing better performance although it allocates several calls with high SIR. The histograms also illustrate how each algorithm allocates call requests.

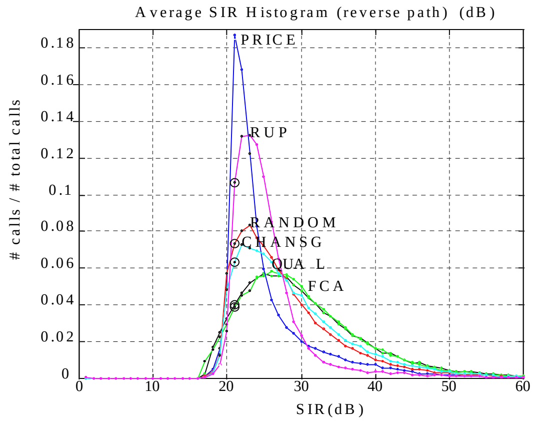

figure 2

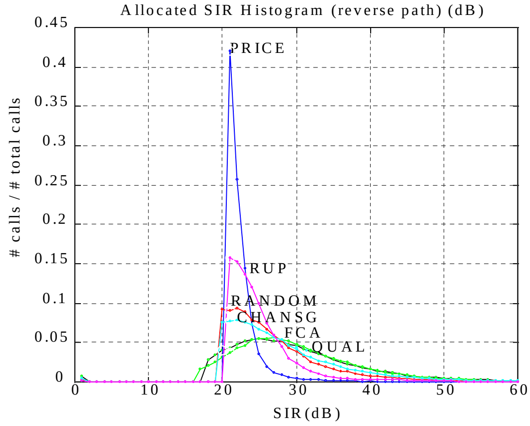

figure 3

The average SIR for each algorithm in the operation point was also collected: FCA: 29.9dB; QUAL: 29.6dB; RANDOM: 27.5dB; CHANSG: 28.6 dB; PRICE: 25.1dB and RUP: 25.1 dB. As expected, although the 10% percentile SIR level was equalized, the average SIR from DCA algorithm was lower than FCA's.

The stability of a DCA algorithm can be analyzed by measuring intracell hand-off rate (interference probability) and the call interruption probability.

All algorithms resulted in interference probabilities ranging from 1,5% (QUAL) through 25% (PRICE) as shown in figure 4. The circles indicate the 4% blocking operation point.

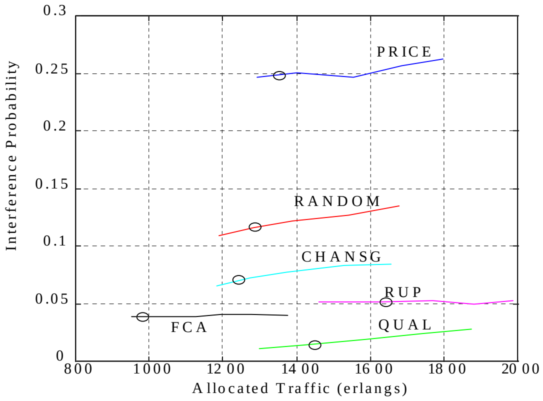

figure 4

The interference probability in each algorithm can be explained based on the way each algorithm allocates channels. Algorithms that allocates channels with SIR close to the minimum SIR, like PRICE and RUP (see figure 3), will have high interference probability since any weak interference from another user will degrade the SIR and trigger an intracell hand-off. Similarly, algorithms that allocate channels with higher SIR, like QUAL (see figure 3), will have margin to stand additional interference that might happen during the course of the conversation.

The average number of intracell hand-offs per call was also computed. The results ranged from 0,03 (QUAL) through 0,5 (PRICE). RUP showed less than 0,1 intracell hand-offs per call. These results are a direct reflect of the interference probability.

Figure 5 shows the interruption probability from all algorithms. The operation point in each algorithm is indicated in this figure confirming that all algorithms resulted in a low interruption probability, close to 2%.

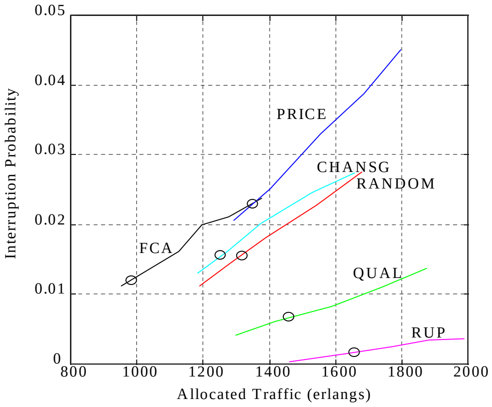

figure 5

As reported by several other articles, power control can improve the performance of IA-DCA algorithms.

6. Power Control Effect

Power control that compensates for the path loss in the link, including the lognormal fading component, was applied in both forward and reverse links. The system was kept interference-limited and the mobile unit and base station would be transmitting at maximum power when the mobile unit is located in the vicinity of the service area. This maximum power was equal to the constant power used in the fixed transmitted power case.

We simulated the power control effect considering communications quality and system stability. Thus, each Acceptance-SIR threshold was set in order to produce the same 10th percentile SIR level over all algorithms and keep interruption probability in a reasonable value (2%-3%). Simulations showed that all DCA algorithms would need an Acceptance-SIR threshold of 19dB (4dB margin over the minimum SIR).

Figure 6 shows the blocking probability for several traffic loads. The capacity gains over FCA were:

QUAL:	84%
PRICE:	94%
RANDOM:	86%
CHANSG:	88%
RUP:	92%

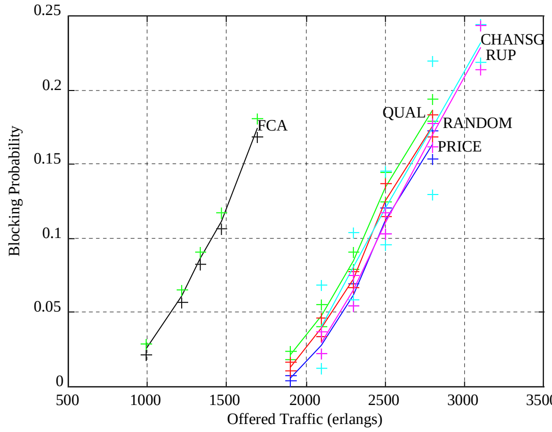

figure 6

As expected, power control increases capacity gains over FCA. These results are explained by the reduced interference level generated by active calls, allowing additional calls to be allocated [6].

In order to evaluate the individual contribution of the power control in DCA algorithms' capacity, the capacities were compared before and after power control was applied. PRICE, RANDOM and CHANSG algorithms showed approximately 60% additional capacity when compared to the same algorithms without power control. QUAL capacity was improved in 80% with the application of power control. This was expected since power control avoids the establishment of calls with too high SIR. Such conclusion can be confirmed by observing the SIR histograms before (figures 2 and 3) and after (figures 7 and 8) the application of power control. RUP did not benefit much from power control, with an increase of just 18% over the fixed-power case. The reuse partitioning theory can explain this low additional capacity for non-ideal cases as verified in [2]. Power control mitigates the penalties in RUP capacity reflected by non-ideal allocations.

Figures 7 and 8 show the SIR histograms of the average and allocated SIR for each algorithm when they are operating at the operation point. From these histograms, we justify the close performance found among all algorithms: since the SIR range was reduced, the channel chosen by an algorithm will not be much different from any other candidate channel. Thus, the differences among algorithms are reduced. Note that QUAL does not allocate calls with very high SIR as in the case of fixed power control.

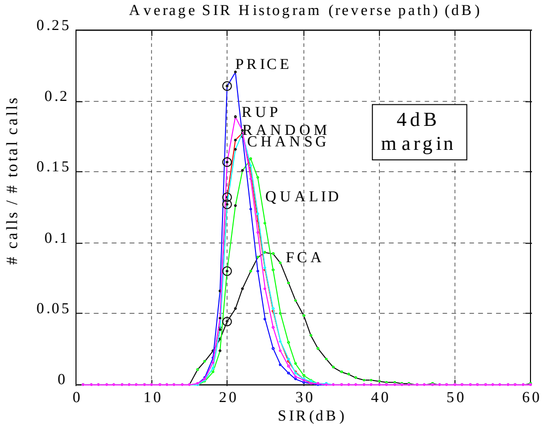

figure 7

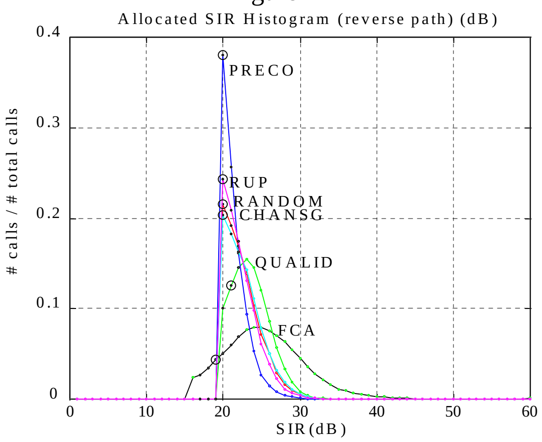

figure 8

Regarding average SIR, DCA algorithms resulted 21dB-23dB while FCA showed a 25dB average SIR.

Regarding stability, the interference probability resulted in values ranging from 17% (QUAL algorithm) and 25% (PRICE algorithm) as can be seen in figure 9. The high values found when power control was applied are easily justified by the Allocated SIR histograms showed in figure 8. The histograms show that the greatest part of the calls had allocated SIRs close to the minimum SIR. If the 4dB-margin in the Acceptance-SIR was not considered, DCA algorithms would show a much poorer performance, with interference probabilities ranging from 40% through 60%.

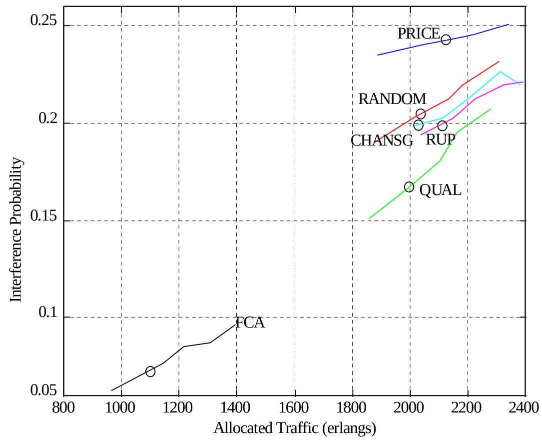

figure 9

Regarding the average number of intracell hand-offs per call, simulations resulted in values ranging from 0,2 (QUAL) through 0,4 (PRICE). If the 4dB-margin in the Acceptance-SIR was not considered, the average number of intracell hand-offs per call would be ranging from 1 (QUAL) through 2 (PRICE) intracell hand-offs per call.

Figure 10 presents the final interruption probability found in all algorithms. FCA's interruption probability was lower than 1% for the operation point. DCA algorithms showed reasonable interruption probabilities, ranging from 2% through 3%. In the non-equalized case (no 4dB-margin), these values would range from 7% (QUAL algorithm) through 15% (PRICE algorithm).

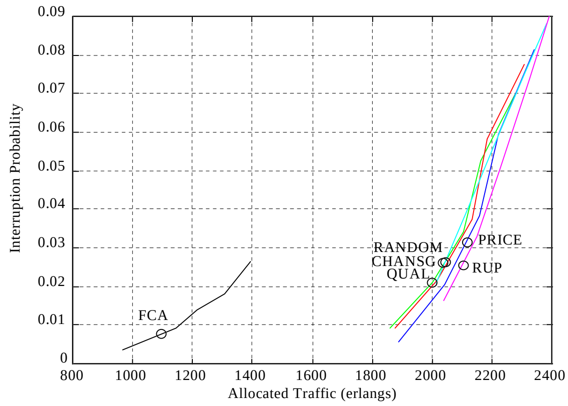

figure 10

Comparing the interruption probability before (figure 5) and after (figure 10) the application of power control, it is possible to note that power control increases the interruption probability in DCA algorithms due to the increased interference probability [9]. Therefore, DCA algorithms should include margin between the Acceptance-SIR and the minimum-SIR in order to guarantee a lower interruption probability, and thus a more stable system.

7. Conclusions

This article has analyzed several different DCA algorithms under the same simulation scenario, allowing a complete comparison among them. It was shown that RUP is the algorithm with best performance in the fixed power control case.

However, when applying power control, all DCA algorithms had close performance. Thus, additional criteria should be used in order to better select one algorithm over another (for example: implementation complexity, time for call setup, etc).

The effect of power control was analyzed separately and we concluded that power control could increase the capacity of DCA algorithms by 20%-80% depending on the algorithm type.

This article has also evaluated the performance of each DCA algorithm among each other and against FCA in equalized conditions. Capacity gains ranged from 48% to 70% in the fixed transmitted power case and from 84% to 94% in the power control case. The increased trunking efficiency and better reuse of channels justify these capacity gains over FCA.

It was also confirmed that interference and interruption probability are figures that should be considered to ensure a stable system, specially in systems using power control.

This article also presented SIR histograms that allowed a better analysis and comparison among algorithms.

Before reach final conclusions about IA-DCA algorithms, other aspects must be studied, like mobility, limitations on the number of transceivers equipped in each cell, time varying traffic patters, SIR-based power control schemes, microcellular systems and TDMA-based systems.

8. References

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