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# Simulation of Interference Avoidance in Cellular Digital Relay Networks using Dynamic Frequency Hopping

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**Abstract**

Cellular Digital fixed Relay networks are new wireless system architecture based on integrating Digital Relay technique in the cellular networks to provide high data rate coverage. Therefore, interest has focused on solving the interference and multipath fading problems which introduce in system because of increasing the resources of signal in cell (Base station, Relays). This paper proposes Dynamic frequency hopping (DFH) as an interference avoidance technique for cellular Digital fixed Relay networks. The simulation of system contains applying Digital Relay and DFH techniques and focuses on the handoff process between Base station and Digital Relay. The simulation results compare the performance of system for two cases; with Relay-without DFH, and with Relay-with DFH. The results indicate that DFH can significantly improve the performance of system. The results show when the cluster size of system consists of seven cells the enhancement ratio is 83% in the blocking probability with high number of calls per hour and increase 15.38% in the number of users. When the cluster size of system consists of thirteen cells, the enhancement ratio is 85% in the blocking probability with high number of calls per hour and increase 15.38 % in the number of users.

## محاكاة تجنب تأثير التداخل في شبكات الانظمة الخلوية ذات المقوى الرقمي باعتماد تقنية ديناميكية القفز الترددي

**الخلاصة**

ان الشبكات الخلوية ذات مُرَّحِلْ الاشارة الرقمي هي انظمة لاسليكة حديثة تحقق تغطية معدل بيانات عالية، و بسبب تعدد مصادر الاشارة ضمن الخلية الواحدة ( برج الارسال والاستقبال ، مقويات الاشارة الرقمية ) تم تركيز الاهتمام على حل مشكلة التداخل ومشكلة خفوت الاشارة واللتان تتولدان ضمن هذه الانظمة الحديثة. ان هذا البحث يقترح استخدام تقنية ديناميكية القفز الترددي كتقنية لتجنب التداخل ضمن الشبكات الخلوية ذات مقوي الاشارة الرقمي اما المحاكاة المقترحة ضمن هذا البحث فقد تضمنت تطبيق كل من تقنيتي مقوي الاشارة الرقمي وديناميكية القفز الترددي وتم التركيز فيها على عملية المناولة ما بين برج الارسال والاستقبال ومقوي الاشارة الرقمي ، لقد تمت مقارنة نتائج المحاكاة على ضوء حالتين الاولى تتضمن تطبيق تقنية مقوي الاشارة الرقمي فقط والثانية تتضمن تطبيق كلا التقنيتين مقوي الاشارة الرقمي وديناميكية القفز الترددي . أظهرت النتائج بان اداء النظام قد تحسن بشكل ملحوظ حيث كانت نسب التحسين لحجم العنقود ذو السبعة خلايا هي 83% في احتمال قطع المكالمات وعند نسبة زيادة عدد مكالمات المستخدمين 15,38 % اما في حالة حجم العنقود ذو الثلاثة عشر خلية فان نسب التحسين هي 85% في احتمال قطع المكالمات وعند نسبة زيادة عدد مكالمات المستخدمين 15,38 %.

## 1- Introduction

Recently there has increase in the concept of augmenting the infrastructure-based networks with multihop communications capability in order to provide high data rate coverage in large areas in a cost efficient manner. Multihop Communications can be facilitated through low-complexity fixed relays (wireless router) deployed by the service providers [1]. With the introduction of relays, the distance that the signal has to travel from/to a

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user decreases and therefore capacity and coverage of the cell increases [2,3]. Relays are very simple devices compared to base stations, which make system considerably cheaper than base stations. Another striking feature of relays is their low transmission power. Therefore, power amplifiers used are much cheaper than those of Base stations. This fact also decreases the cost of the system [4].

However, using Digital Relay in cellular networks leads to increase the interference since the Digital Relay is considered as new source of interference. The amount of this interference depends on the number of Digital Relays employed in one cell. A number of techniques are used to solve the interference in cellular systems. Some of these are channel coding and interleaving, adaptive modulation, transmitter/receiver antenna diversity, spectrum spreading and dynamic channel allocation [5].

In this paper DFH technique is proposed to solve this problem. The main idea of DFH incorporates a non-traditional Dynamic Channel Allocation (DCA) scheme with Slow frequency hopping (FH). Integrating relaying concept with DFH increases data rate coverage. This enhancement consists of increasing the S/I ratio to acceptable levels. Since the $P_B$ is defined as the probability that the signal to interference ratio (S/I) is less than a specified threshold i.e., $P_B \triangleq P[S/I < \eta]$ this results in decreasing the Blocking probability ($P_B$) to acceptable level [5]. Therefore in this paper the performance of the system is analyzed depending on the $P_B$ which is determined by using Erlang B formula as follows [6].

$$P_B = \frac{\binom{u-1}{c}(\ell h)^c}{\sum_{i=0}^{c}\binom{u-1}{i}(\ell h)} \qquad (1)$$

Where u *and* c are the number of users and channels, respectively. ℓ and h are the number of calls per hour and average calling time, respectively.

In this paper the proposed system architecture of cellular Digital fixed Relay network is shown in Figures (1), (2). Where three Digital Relays are put in the areas that are not covered by Base station, these areas are known as coverage holes (dead spots), with distance between of the Relay location and the edge of cell equal to fifth of cell radius.

## 2. Radio Propagation Model

Wireless waveforms propagating through free space are subject to a distance-dependent loss of power, called path loss. The received power at distance (d) ($d \geq d_0$ m) from a transmitter is described by the Friis free-space equation [7].

$$P_{rcvd}(d) = \frac{P_{tx}.G_t.G_r.\lambda^2}{(4\pi)^2.d^2.L} = \frac{P_{tx}.G_t.G_r.\lambda^2}{(4\pi)^2.d_0^2.L}.\left(\frac{d_0}{d}\right)^2 = P_{rcvd}(d_0).\left(\frac{d_0}{d}\right)^2 \qquad (2)$$

where $P_{tx}$ is the transmission power, $G_t$ and $G_r$ are the antenna gains of transmitter and receiver, $d_0$ is the so-called far-field distance, which is a reference distance depending on the antenna technology, $d \geq d_0$ is the distance between transmitter and receiver, $\lambda$ is the wavelength and $L \geq 1$ summarizes losses through transmit/receive circuitry. Note that this equation is only valid for $d \geq d_0$. A

$$P_{revd}(d) == P_{revd}(d_0).\left(\frac{d_0}{d}\right)^{\gamma} \quad ....(3)$$

generalized model which is valid also for other environment is [7]:
Where γ is the path-loss exponent, which typically varies between 2 (free-space path loss) and 5.5 (shadowed areas and obstructed in-building scenarios). However, values γ < 2 are possible in case of constructive interference. The path loss is defined as the ratio of the radiated power to the received power and can be expressed in decibel as [7]:

$$PL(d)[dBm] = PL(d_0)[dBm] + 10\gamma \log_{10}\left(\frac{d}{d_0}\right) \quad ...(4)$$

This is the so-called log-distance path loss model. $PL(d_0)[dBm]$ is known as path loss at the reference distance d. The variation in the received signal power, when measured in a log scale (in dBm), has a Normal distribution. The depth of this fade variation is measured by the standard deviation and represented by σ. Thus, in order to account for the effect of shadow fading, equation (2) can be further written as [8,9]:

$$P_{revd}(d) = \frac{P_{tx}\,.\,G\,.\,\lambda^2}{(4\pi)^2.d^2.L} X_\sigma \qquad (5)$$

Where $G= G_t \,.\, G_r$ is combined antenna gain of the transmitter and the receiver, $X\sigma$ is Log-normally distributed random variable with (0dBm) mean, σ (dBm) standard deviation.

## 3. Dynamic frequency hopping

Dynamic frequency hopping is a combination of dynamic channel assignment (DCA) and the traditional frequency hopping, where a channel is one frequency in a frequency hop pattern, [4,10]. An ideal DFH method works in the following way .At each hopping instant, instead of hopping randomly or according to some predetermined repetitive pattern, the BS or mobiles measure the quality of each frequency, filters the measurement, and thereafter sends the data using the best frequencies chosen according to some criterion [5]. The main objective from DFH is to provide capacity improvements through the addition of interference avoidance, which are higher than those provided by conventional FH, while preserving interference averaging characteristics of conventional FH in order to provide robustness to changes in interference [4].

### 3.1 Methods of dynamic frequency hopping

There are four methods as follow.

1) **Full-replacement method**
All frequencies used in one frame are replaced with better frequencies in the next frame. This guarantees that during an entire transmission, frequencies with the best quality are used. FH pattern modifications are done in a centralized fashion at each base station for all of the base station's mobiles. This method gives the best possible performance of all dynamic frequency-hopping methods. Rapid measurements of interference, SIR, or other quality-variables are required for all available system frequencies. This method creates heavy messaging overhead over the air for

exchanging the data about new frequency-hop patterns [5].

2) **Worst dwell method**
To achieve a satisfactory system performance, it is enough to periodically change only one of the used frequencies the one with the worst quality (highest interference, lowest SIR, etc.) in the frequency hop pattern [5].

3) **SIR threshold-based method**
In this method, the pattern change is done sparingly. In each frame, SIR is measured on the used frame frequencies and the current hopping pattern is changed if the measured SIR does not achieve the required threshold on at least one of them. Only the frequencies in poor conditions are changed. Any frequency that meets the threshold can be used as a replacement, and there is thus no need to scan all possible frequencies [5].

**4) The received power threshold Method**

In this method the calculated received power for frequencies in frame is compare with a threshold value, and blocking any frequency, which generates the weak received power, then replace this frequency by new frequency from the next frame [11].

## 4. Proposed Simulation Model

In this paper, the proposed simulation model for cellular fixed Digital Relay networks using DFH is arranged in steps below as shown in flowchart of figure 3

### 4.1 Arrangement the pattern of random frequency

The program generates the random frequencies, the center frequency is (900 MHz) at channel spacing (50 MHz). The frequencies arrangements as frames, each frame consist of six slots (six random frequencies).

### 4.2 Random user generation

In this section allocation random frame is defined for subscriber in cell, for communication with another subscriber.

### 4.3Determining of subscriber location

Determining of subscriber location will be done to find out the location of subscriber that is if the user is in the coverage area of BS or in the one of coverage areas of Relay in cell. Accordingly a channel would be allocated to communicate with BS or Relay.

**4.4 The communication with BS or Relay:**When the subscriber is found in the coverage area of BS, the communication is between subscriber and BS. On the other hand, when the subscriber is found in the coverage area of Relay, the communication is between subscriber and Relay. This communication contains some steps as follows:

#### 4.4.1 Determining of communication channel

Allocate any communication channel which is not in use in cell for executing the communication between subscriber and BS or Relay. In the present work this paper does not depend on mechanism of allocating channels to each Relay as we have seen in other studies [12-15]. However, here all channels are under control of the BS, which determines the suitable communication channel for communication between BS and User or Relay and User.

#### 4.4.2Calculating the received signal power for frequencies in the frame

Depending on equation (5), the program calculates received powers for six frequencies of one frame. The values of received powers are stored in matrix (M1). This continues until the end of communication process.

### 4.4.3 Applying the DFH technique

After transmitting the matrix (M1) for communication we apply the DFH technique to guarantee the best values of received power for any transmit frame. This technique consists of the following steps: -

1- Recall the calculated received power for six frequencies in one frame and compare it with the threshold value of -76 dBm. Block any frequency, which generates power which is less than (-76 dBm)[11].
2- Replace this frequency by new frequency from any unused frame.
3- Calculate the received power for the new frequency and compare it with the threshold value (-76) again.

The calculated value of received power is recalled and compared with threshold value. If the calculated value of Pr is greater or equal to the threshold value (-76 dBm) (for example -70,-60) then this value is stored in new matrix (M2) for handoff process and at the same time this value is sent to continue the communication process. When Pr is less than the threshold (-76 dBm) (for example -80,-100) which is caused by multipath fading and interference problems, the system blocks this frequency and replaces it with new frequency from unused frame and recalculates the Pr and compares with the threshold value (-76) again. The DFH process is repeated until the communication process ends.

### 4.5 The handover between BS and Relay

At the end of comparing all frequencies of frame and store them in matrix (M2) the systems recalls these frequencies again to compare them with new threshold value (-71) which is used to determine keeping the communication with BS or transition to the closer Relay of subscriber or inversion. If the value of Pr is greater than threshold value (-71) then it is stored in matrix (M3) but if the value of Pr is less than threshold value (-71) then it is stored in matrix (M4). After ending the comparison process of the Pr values stored in matrix (M2), the system compares the number of values in matrix M3 with on M4. Now there are two cases to handover, the first is when the subscriber moving from BS to Relay, secondly when the subscriber moving from Relay to BS.

In the first case (BS to Relay)($M_3 < M_4$) if the number of values stored in matrix (M4) is larger than the number of values stored in matrix (M3), then the communication is transformed from BS-subscriber to Relay-subscriber with allocating suitable communication channel. However, ($M_3 > M_4$) when the number of values in matrix (M4) is less than the number of values in matrix (M3), then the communication is continued between BS and subscriber.

In second case (Relay to BS)($M_3 > M_4$) if the number of values in matrix (M3) is larger than the number of values in matrix (M4), then the communication is transformed from Relay-subscriber to BS-subscriber with allocating suitable communication channel. However, ($M_3 < M_4$) when the number of values in matrix (M3) is less than the number of values in matrix (M4), then the communication continued between Relay and subscriber. This process continued until ending the communication process.

## 5. Simulation Results

This paper presents the simulation results for all suggestions in previous sections. The objectives of this simulation are to improve the performance of cellular fixed Relay networks by using DFH technique. These are presented in accordance with the comparison between two proposed cases as follows:-

1-With Relay -Without DFH.
2-With Relay -With DFH.

### 5.1 Blocking Probability

This section aims to study the changes in $P_B$ through two main parts:-

1-Blocking probability with load traffic.

2-Blocking probability with user.

For the first part there are two factors influence the load traffic (number of calls per hour (ℓ) and average calling time (h) to observe how the $P_B$ is changing. In the second part depends on the number of users only and shows the effect of increasing the number of user on $P_B$.

#### 5.1.1 Blocking Probability with Load Traffic

This section includes Figures (4) and (5) for K=7, 13 respectively, when the number of calls is equal to 15 per hour and average calling time equals 2 minute. In Figure (4) $P_B$ in first case (with Relay -without DFH) equal to 0.0024 in load traffic equal to 50, and then increase to 0.0606 in load traffic equal to 65. The best values of $P_B$ found in second case (with Relay - with DFH) is equal to $1.243\times10^{-3}$ in load traffic equal to 50, and 0.0188 in load traffic equal to 65. Approximately the same behavior when K= 13 in Figure (5) but with good enhancement ratio for $P_B$ . In first case (with Relay -without DFH) $P_B$ equals 0.0018 in load traffic equal to 50 and 0.0538 in load traffic equal to 65. In the second case (with Relay - with DFH) $P_B$ equals $8\times10^{-5}$ in load traffic equal to 50, and 0.0156 in load traffic equal to 65.

Figures (6) and (7) for K=7, 13 respectively, when the number of calls is equal to 25 per hour and average calling time equals 2 minute. In Figure (6) the $P_B$ equal to $4.511\times10^{-4}$ for first case (with Relay -without DFH) and $1.154\times10^{-5}$ in second case (with Relay-with DFH) when load traffic equals 45.83(number of users are 55). When load traffic increase to 62.5 (number of user are 75) $P_B$ equals 0.0482 in first case (with Relay-without DFH) and 0.012 for second case (with Relay-with DFH). Figure (7) gives the same behavior when the K= 13. When the load traffic equals 45.83 $P_B$ equals $2.99\times10^{-4}$ in first case (with Relay - without DFH) and $6.872\times10^{-6}$ for second case (with Relay-with DFH).When load traffic increase to 62.5 $P_B$ equals 0.0418 in first case and 0.0097 for second case. Then it is increase the number of calls to 35 per hour with 1 minute for average calling time in Figures (8) and (9). In Figure (8) When load traffic equal to 46.667(number of users are 80) $P_B$ for first case equal to $6.416\times10^{-4}$, $1.89\times10^{-5}$ in the second case. The same case in Figure (9) when the K= 13, the $P_B$ in the load traffic 46.6667 is equal to $4.337\times10^{-4}$ in first case (with Relay-without DFH) and $1.149\times10^{-5}$ for second case (with Relay -with DFH). When increase the load traffic to 64.1667 (number of users are 110) in both figures the values of $P_B$ in the second case (with

Relay-with DFH) remains less than criteria value 0.02.

From these results, the enhancement range is observed in $P_B$ when it uses DFH techniques in this network. Especially in the second case (With Relay- with DFH) where the values of $P_B$ still good and less than criteria value (0.02) comparing with first case, in spite of the load traffic increased. That means it can be increase the number of users in any cellular network when applying DFH technique. This enhancement in $P_B$ leads to high reliability in communication operation through call period, in addition it transmits high data rates.

**5.1.2 Blocking Probability with User**

Figure (10) presents good enhancement when we apply DFH. We can see in the first case (With Relay- Without DFH) when the number of users is equal to 65, $P_B$ equals 0.0096 and increases to 0.0245 when the number of users increases to 70. In the second case (With Relay- With DFH) when the number of user equals 75, $P_B$ equals 0.012, and increases to 0.0272 when number of users increases to 80, which means any cellular network can be increase the number of users by applying DFH technique. In Figure (11), it can be seen the same behavior approximately.

**6. Conclusions**

Our results show that the DFH technique can be improve the system performance. Therefore, based on our simulation results, the following conclusions are drawn:-

1-The results show a good enhancement in the $P_B$ when applying DFH technique to solve the interference problem as follows:-

A- When $\ell$ =15, h=2 and K=7 the enhancement ratio between first case (with Relay-without DFH) and second case (with Relay-with DFH) is equal to 68.9% approximately .when K=13 this ratio increases to 71%.

B- When $\ell$ =25, h=2 and K=7 the enhancement ratio between first case (without Relay-without DFH) and second case (without Relay-with DFH) is equal to 75% approximately .when K=13 this ratio increases to 76.77%.

C- When $\ell$ =35, h=1 and K=7 the enhancement ratio between first case (without Relay-without DFH) and second case (without Relay-with DFH) is equal to 71% approximately .when K=13 this ratio increases to 73%.

2-The results of $P_B$ with respect to number of user indicate two important points, they are:-

-The enhancement ratio in number of user between the first and second cases is 15.38% for K=7 and K=13, which means any cellular fixed relay networks can increase the number of user by applying DFH technique.

-The enhancement ratio in $P_B$ between the first and second cases is 30% for K= 7 and 35.6% for K=13, that means increase in the system capacity when applying DFH technique.

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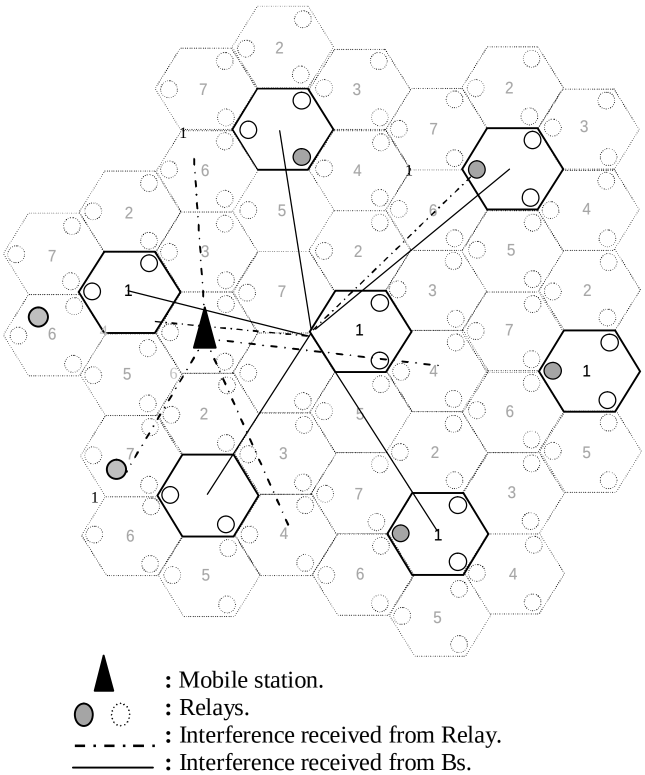



**Figure (1) The interference sources (BS ,Relays) when the cluster size is equal to7**

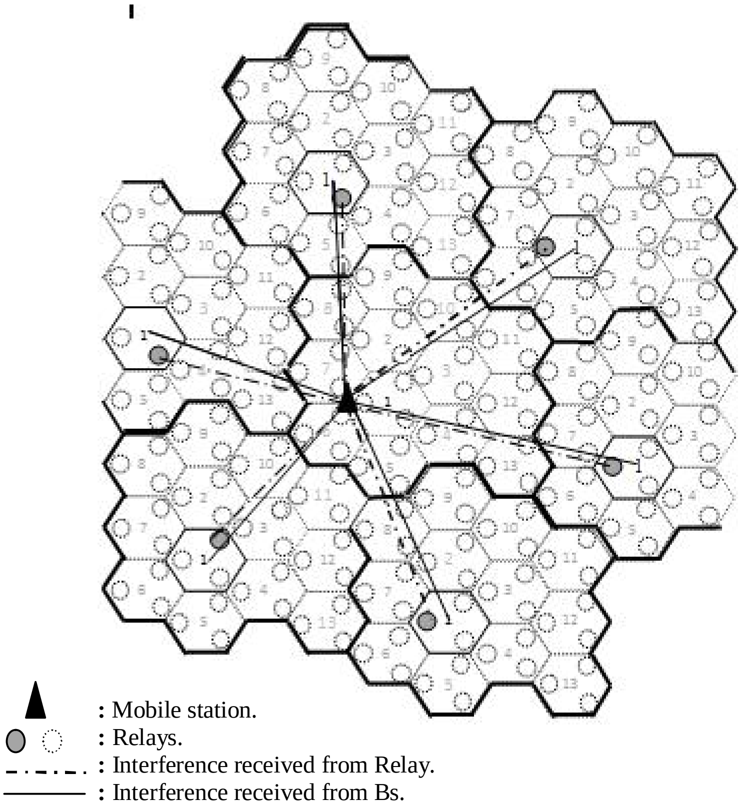
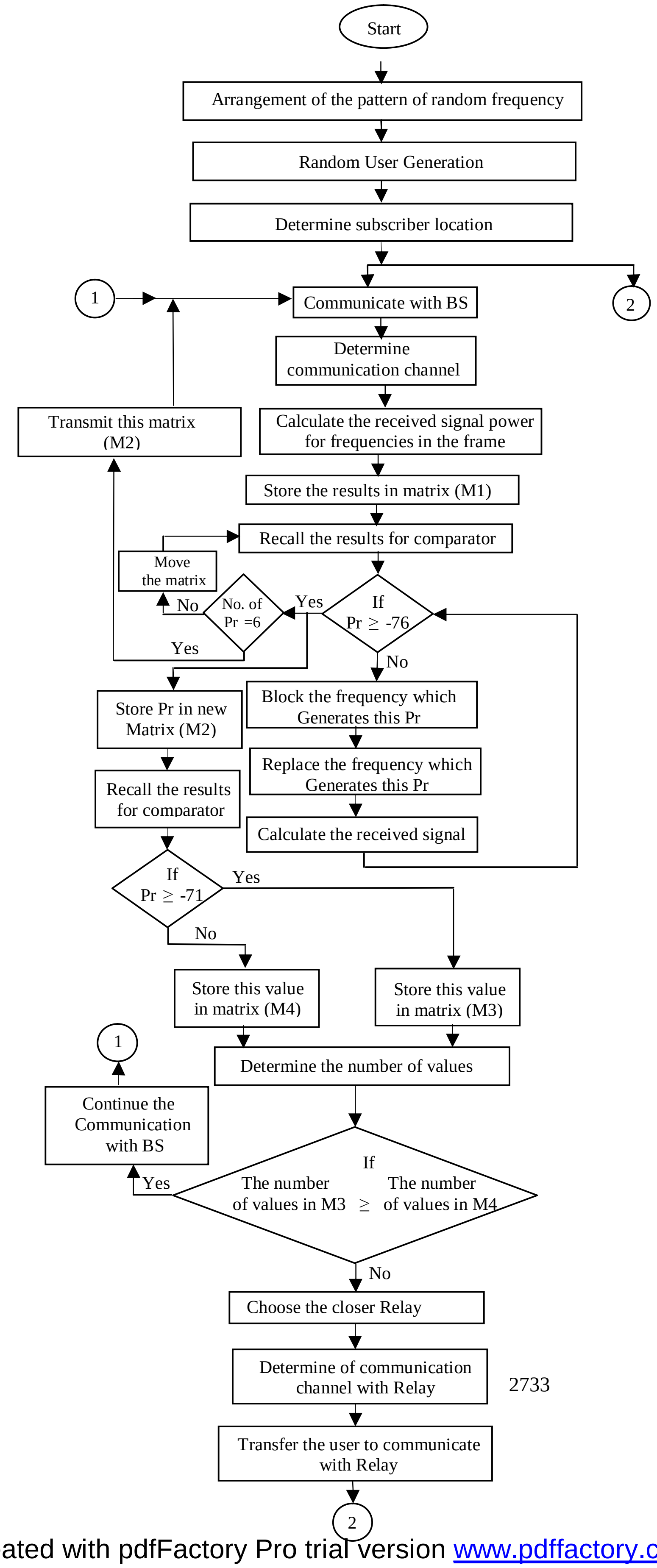



**Figure (2) The interference sources (BS, Relays) when the cluster size is equal to 13**.


Start
Arrangement of the pattern of random frequency
Random User Generation
Determine subscriber location
1
Communicate with BS
2
Determine communication channel
Transmit this matrix (M2)
Calculate the received signal power for frequencies in the frame
Store the results in matrix (M1)
Recall the results for comparator
Move the matrix
No
No. of Pr =6
Yes
If Pr ≥ -76
Yes
No
Store Pr in new Matrix (M2)
Block the frequency which Generates this Pr
Replace the frequency which Generates this Pr
Recall the results for comparator
Calculate the received signal
If Pr ≥ -71
Yes
No
Store this value in matrix (M4)
Store this value in matrix (M3)
1
Determine the number of values
Continue the Communication with BS
Yes
If The number of values in M3 ≥ The number of values in M4
No
Choose the closer Relay
Determine of communication channel with Relay
Transfer the user to communicate with Relay
2

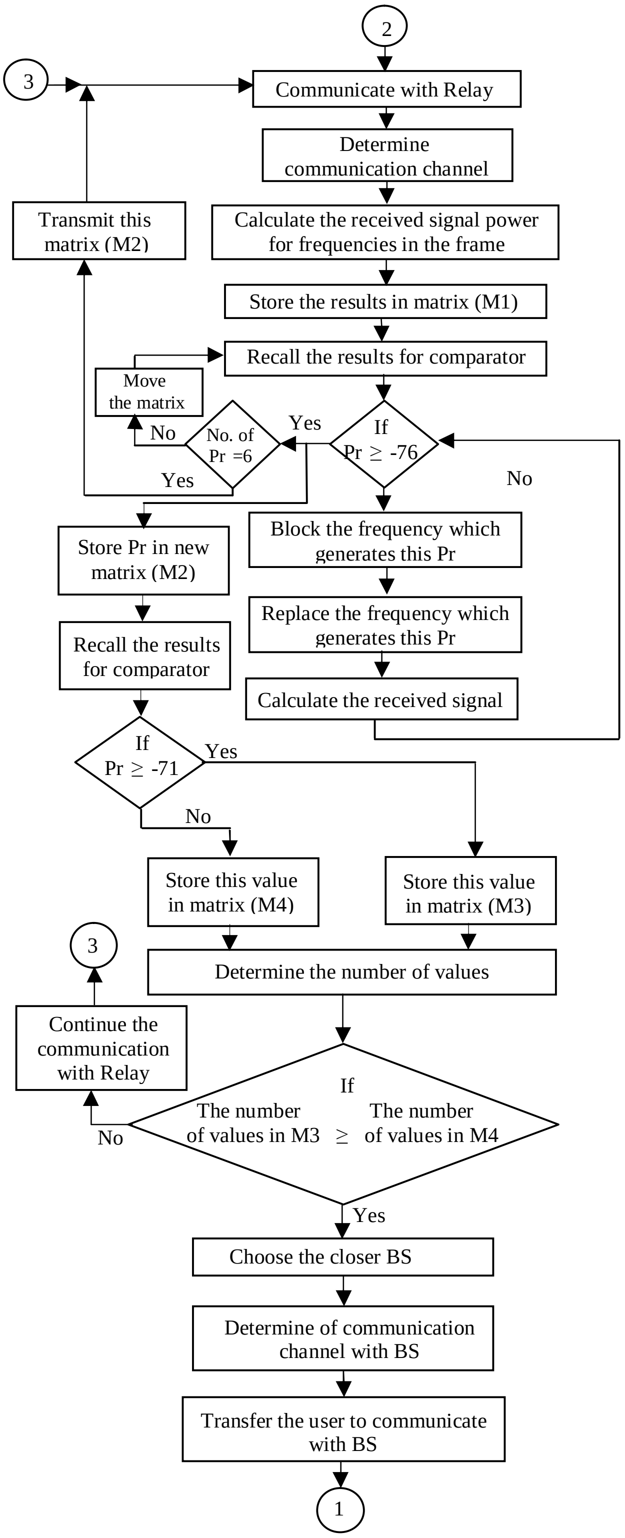



**Figure (3) Simulation flowchart for operating Relay and DFH techniques in cellular system**

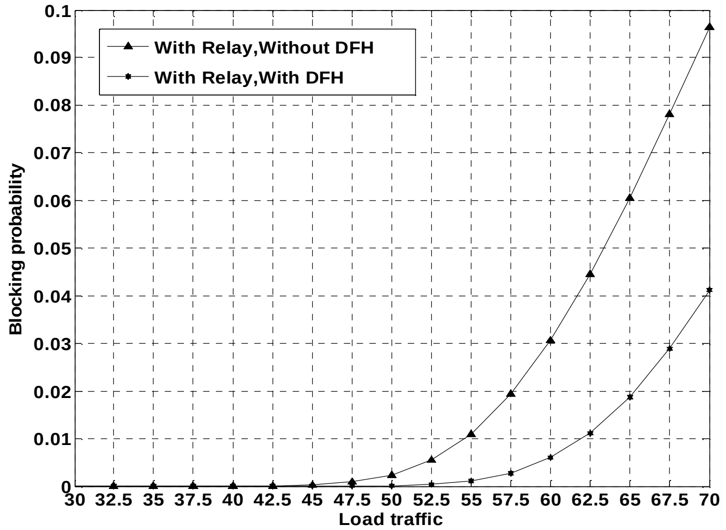



**Figure (4) The relationship $P_B$ and load traffic when K = 7, number of calls = 15 per hour, average calling time = 2 minute**

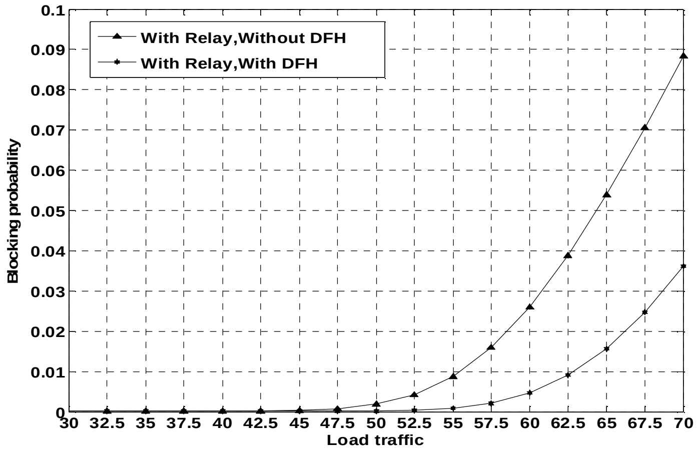



**Figure (5) The relationship between $P_B$ and load traffic when K = 13, number of calls = 15 per hour, average calling time = 2 minute**

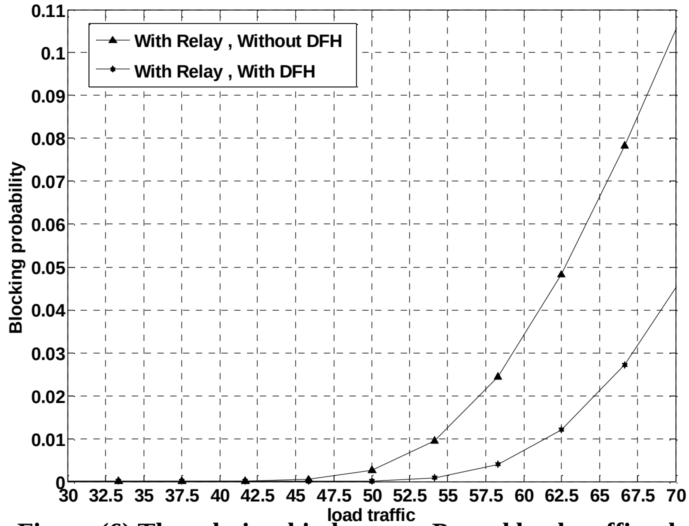



**Figure (6) The relationship between $P_B$ and load traffic when K = 7, number of calls =25 per hour, average calling time = 2 minute**

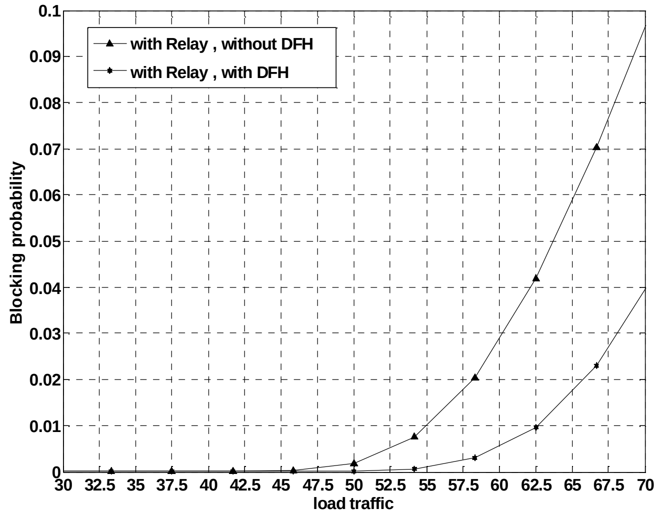



**Figure (7) The relationship between $P_B$ and load traffic when K = 13, number of calls =25 per hour, average calling time = 2 minute**

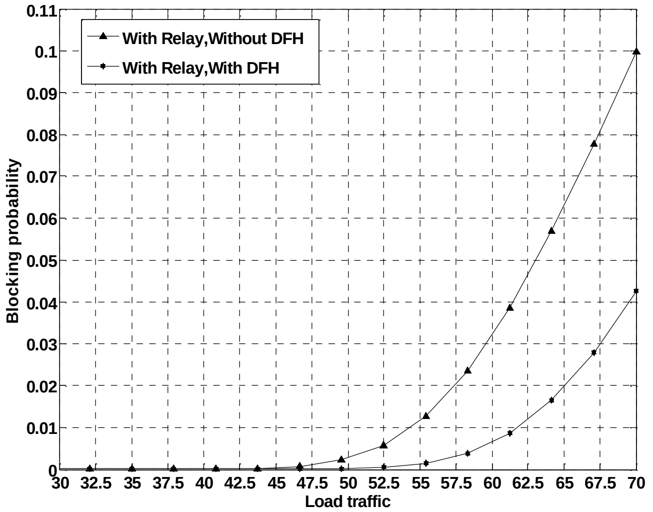



**Figure (8) The relationship between $P_B$ and load traffic when K = 7, number of calls =35 per hour, average calling time = 1 minute**

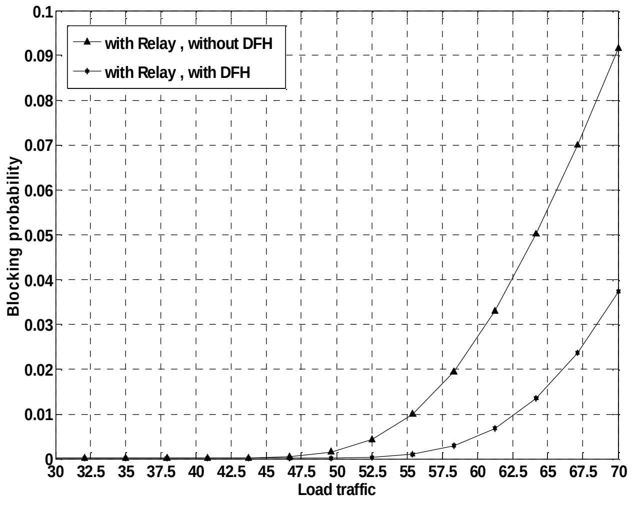



**Figure (9) the relationship between $P_B$ and load traffic when K = 13, number of calls =35 per hour, average calling time = 1 minute**

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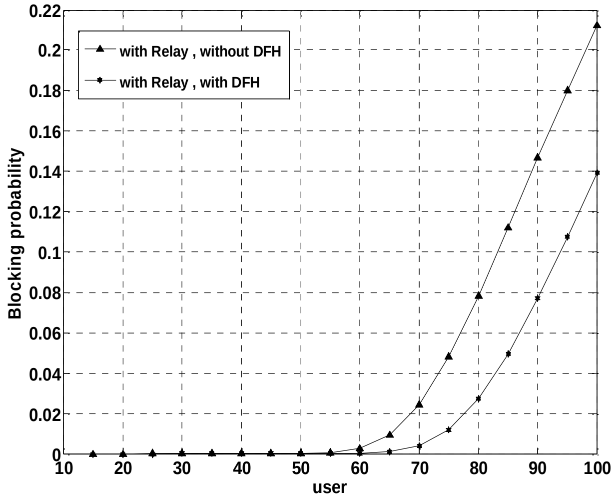


**Figure (10) The relationship between $P_B$ and users when K = 7**

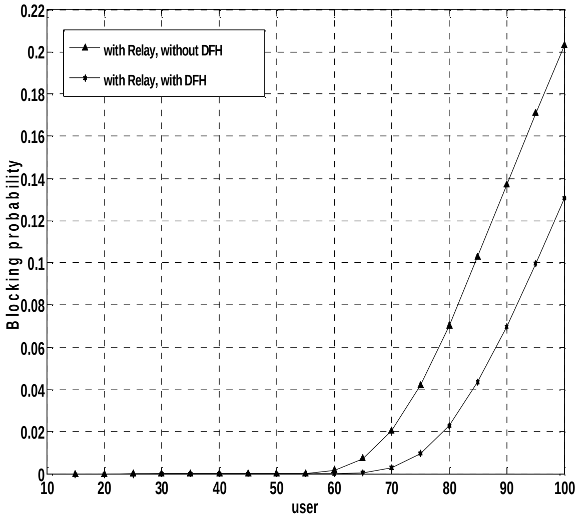


**Figure (11) The relationship between blocking probability and users when K = 13**