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New hybrid frequency reuse method for packet loss minimization in LTE network

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ABSTRACT

This paper investigates the problem of inter-cell interference (ICI) in Long Term Evolution (LTE) mobile systems, which is one of the main problems that causes loss of packets between the base station and the mobile station. Recently, different frequency reuse methods, such as soft and fractional frequency reuse, have been introduced in order to mitigate this type of interference. In this paper, minimizing the packet loss between the base station and the mobile station is the main concern. Soft Frequency Reuse (SFR), which is the most popular frequency reuse method, is examined and the amount of packet loss is measured. In order to reduce packet loss, a new hybrid frequency reuse method is implemented. In this method, each cell occupies the same bandwidth of the SFR, but the total system bandwidth is greater than in SFR. This will provide the new method with a lot of new sub-carriers from the neighboring cells to reduce the ICI which represents a big problem in many applications and causes a lot of packets loss. It is found that the new hybrid frequency reuse method has noticeable improvement in the amount of packet loss compared to SFR method in the different frequency bands. Traffic congestion management in Intelligent Transportation system (ITS) is one of the important applications that is affected by the packet loss due to the large amount of traffic that is exchanged between the base station and the mobile node. Therefore, it is used as a studied application for the proposed frequency reuse method and the improvement in the amount of packet loss reached 49.4% in some frequency bands using the new hybrid frequency reuse method.

Introduction

LTE is one of the most interesting fields of research due to its higher data rate, low latency, high spectral efficiency and improved Quality of Service (QoS) even for the cell edge users [1–3]. The LTE network contains two main parts [3]. The first part is Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and consists of user equipment (UE) and base

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stations. A base station is called enodeB (eNB) in the LTE mobile system. This eNB is responsible for all radio functionalities, resource management, admission control, scheduling and handover process. The second part is the Evolved Packet Core (EPC); it consists of the Serving Gateway (SGW) responsible for user plane and the Mobile Management Entity (MME) responsible for control plane. EPC is connected to the external server using the Packet Data Network gateway (PDN) which is the gateway to any external IP network. LTE is robust against the dispersive channels that suffer from frequency selective fading by using Orthogonal Frequency Division Multiple Access (OFDMA) in the downlink [4,5]. In OFDMA, the whole system bandwidth is divided into a number of orthogonal sub-carriers or Physical Resource Blocks (PRBs). The sub-carrier bandwidth is chosen to be smaller than the system coherence bandwidth which makes the OFDM symbol time greater than the system coherence time and by using appropriate cyclic prefix, the inter-symbol interference (ISI) is completely avoided [5]. The data of different users in the same cell are transmitted in parallel on the different sub-carriers; the inter-carrier interference among the different users is completely mitigated due to the orthogonality among the sub-carriers [6,7]. However, OFDMA suffers from the problem of the inter-cell interference (ICI) or the co-channel interference (CCI) especially for users located at the cell edge [8,9]. This interference is produced due to the radiated power by base stations of neighboring cells that use the same communication band. Therefore, different solutions are implemented to solve this problem and to improve the performance of the cell edge users [10]. The most efficient method is the frequency reuse method with reuse factor greater than one to reduce the interference at the expense of the whole system bandwidth [11]. Different frequency reuse (FR) methods are introduced such as Hard Frequency Reuse (HFR), Fractional Frequency Reuse (FFR) and Soft Frequency Reuse (SFR) [11,12]. In HFR, the whole system bandwidth is divided into number of distinct sub-bands according to the used reuse factor and each cell uses a different sub-band to avoid interference with the neighboring cells [13]. In FFR, the whole system bandwidth is divided into two distinct parts, the inner part and the outer part; the inner part is reused by all base stations for the users that are located closer to the cell center [13]. The outer part is re-divided into three distinct sub-bands and each cell uses a separate sub-band for the users located at the cell edge. In SFR, the whole system bandwidth is used by all cells and power control is applied for various users according to their locations, close to or far away from the base station to mitigate the ICI [14].

In this paper, the problem of ICI is investigated due to its negative impact on receiving the transmitted packets at the mobile node (causing loss of packets [9]). SFR is used because it is the most common frequency reuse method [14]. In order to improve performance, a new method of frequency reuse is developed. This method can be considered as a compromise between the SFR that has high capacity and the FFR that has small ICI (a hybrid technique). Although, the packet loss due to the ICI is a big problem regardless of the applications, there are some applications that are very sensitive to packet loss such as traffic management in Intelligent Transportation System (ITS) [15]. Therefore, traffic management in ITS is chosen to be the studied application for the proposed frequency reuse method.

The paper is organized as follows; the description for the frequency reuse methods used in this research and the -implementation of the new hybrid FR method are discussed in Methodology. The network architecture, the system model and the simulation results are described in Results. The justifications for these results will be described in Discussion. Finally, the paper is summarized in Conclusion.

Methodology

As mentioned before, SFR is used in this work due to its high spectral efficiency and high capacity. However, SFR suffers from ICI especially for the cell edge users because of reusing the whole available bandwidth by all cells [14]. This interference affects the communication between eNB and UE and causes large amounts of packet loss as will be described in Results. Therefore FFR was implemented to mitigate this interference at the expense of the system bandwidth, in which the total system bandwidth is divided into two parts; the first part represents half of the total system bandwidth and the second part represents the second half and is divided into three parts as shown in Fig. 1 [12,13]. Using this method, each cell uses approximately two thirds of the total system bandwidth which causes the capacity of FFR to be smaller than the capacity of SFR. Therefore, in this paper a new method of frequency reuse, that is a compromise between SFR and FFR, is implemented.

In this method, each eNB will use a different center frequency from the neighboring cells to avoid the ICI and this is implemented by increasing the total system bandwidth to be different from the cell bandwidth. The total system bandwidth represents one and a half times the cell bandwidth to provide a guard gap between the different center frequencies allocated to the different eNBs. This guard gap will allow each eNB to have a part of the new frequencies (sub-carriers) which is unused by the neighboring cells; this leads to decreasing the ICI. For the investigated example described below, the bandwidth per cell is 10 MHz (same as SFR) and the total system bandwidth is 15 MHz (one and half times the cell bandwidth). This additional 5 MHz is added to allow 25% of the cell bandwidth (2.5 MHz) to be used as a guard gap between the different carrier frequencies. Therefore, some cells will have at least 25% of the cell bandwidth (2.5 MHz which is approximately equivalent to 13 PRBs, each with 180 kHz) unused in neighboring cells while other cells will have 50% of the cell bandwidth unused in neighboring cells. In this paper, the used frequency band is around 2.5 GHz and a reuse factor of 3 is used. Therefore according to the new implemented method, the used carrier frequencies will be 2.5, 2.5025 and 2.505 GHz or 2.4975, 2.5 and 2.5025 MHz (to be centered around 2.5 MHz) to allow 5 MHz to be unused for some cells and 2.5 MHz to be unused for the others as shown in Fig. 2. This means that each cell will have many new sub-carriers that are not used by the neighboring cells which lead to reducing the ICI and improving overall performance when compared to the SFR method. However, this method has a disadvantage which is the need to increase the total system bandwidth by 50% over the cell bandwidth (for example, if the bandwidth per cell is 10 MHz, the total system bandwidth must be 15 MHz), but the benefits of this new method are expected to overcome the benefits of FFR using the same system

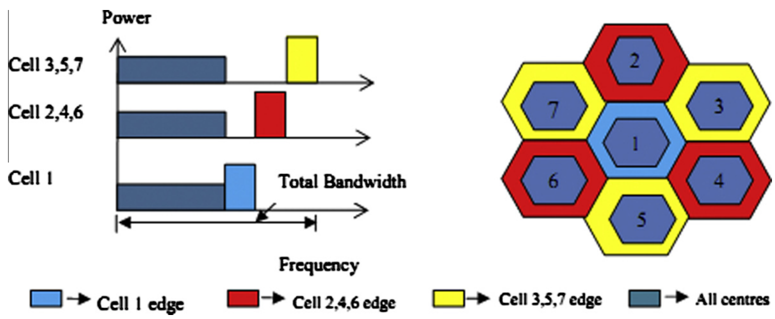

Fig. 1 The implementation of fractional frequency reuse method.

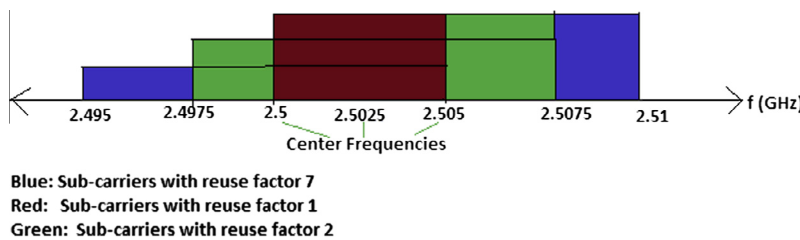

Fig. 2 The implementation of the new hybrid frequency reuse method.

bandwidth. The reason for that is the ability of the new method of introducing a larger number of new sub-carriers for each cell than the FFR; in FFR, each cell has at maximum 25% of the system bandwidth as a new band, but in the new method some cells can have up to 50% of the system bandwidth as a new band. Therefore the number of unused sub-carriers in the new method in each cell is greater than in the FFR and SFR. Consequently, the packet loss due to ICI will be reduced in the new method. Before examining this method in any application, one of the measured parameters of FFR is computed here to validate this new method. The parameter is called probability of coverage; it computes the probability of a very important factor which is the signal to interference and noise ratio (SINR) that is a measured factor for the ICI. It computes the probability that the SINR of the mobile node at any location inside the cell is greater than a certain value as shown in Eq. (1). This certain value is a target threshold; below this threshold, the received signal from the mobile node can be considered as noise.

$$p_{c_j} = \text{prob}(\text{SINR}_j > T) \tag{1}$$

where p_{c_j} is the probability of coverage of user j, T is the target threshold value for the SINR and SINR_j is the SINR of user j and it is calculated according to the following equation.

$$\text{SIN}R_j = \frac{S_j}{N_{TH} + I} = \frac{\text{SN}R_j}{1 + \sum_{i \neq j} \text{SN}R_i} \tag{2}$$

and I is given by

$$I = \sum_{i \neq j} S_i \tag{3}$$

where I is the interference from the neighbor cells in Watts, S_j is the received power by user j and N_{TH} is the thermal noise.

The SINR in Eq. (2) is calculated according to Thapa and Chandra [13] by considering that the network consists of more than one eNB and many UEs around each eNB, then the mobile node moves from the cell edge to the cell center and records the SINR at each point in the cell. Fig. 3 shows two curves; the blue curve represents the probability of coverage of FFR for different threshold values of SINR. The red curve represents the probability of coverage of the new hybrid FR method for the same threshold values of SINR. The red curve is computed according to the proposed network parameters that are mentioned in Table 1, and the blue curve is obtained from Thapa and Chandra [13] where not all parameters were specifically mentioned. However, all parameters mentioned in Thapa and Chandra [13] were used for computing the probability of coverage of the new hybrid method. It is observed from the curves in Fig. 3 that the probability of coverage for the new method follows the same trend as that of the FFR, which validates the new method. It is important to note that

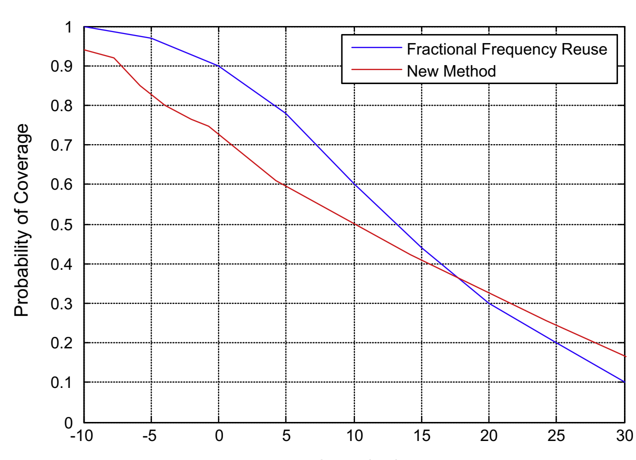

Fig. 3 The probability of coverage for FFR and the new hybrid FR method.

Table 1 Network parameters.

Parameter	Value
eNB	
Transmit power	10 W
Antenna gain	15 dBi
MIMO	2×2
System bandwidth	10 M*Hz*
Rx sensitivity	−123 dBi
Duplexing technique	TDD
Antenna height (h_b)	30 m
UE	
Transmit power	0.2 W
Antenna gain	0 dBi
MIMO	1×2
Rx sensitivity	−106 dBi
Shadow fading standard deviation	4 dB

the comparison between the two curves, while not being very fair since the parameters are not identical, is just used in this research to validate the proposed method.

In this paper, the performance of the investigated FR methods (SFR and the new hybrid FR method) is measured in terms of the amount of packet loss; however other measured parameters are computed such as the handover delay (T_{HO}), the Path loss (P_L) and the bandwidth utilization (B_U). They are commonly used for the SFR and calculated according to the following equations.

Firstly, the handover delay is defined as follows [16]:

$$T_{HO} = t_{search} + t_{IU} + 20\ ms + t_{processing} \quad (4)$$

where t_{search} is the time required to identify the cell if it is unknown, t_{IU} represents the uncertainty of acquiring the first available random access occasion, 20 ms represents the implementation margin and $t_{processing}$ is the time during which UE processes the required message and produces a response [16]. The path loss is given by the following equation.

$$P_L = 40(1 - 4\times10^{-3}h_b)log_{10}(R) - 18\log_{10}(h_b) + 21\log_{10}(f_c) \quad (5)$$

where f_c is the carrier frequency in MHz, h_b is height of the base station in meters and R is the distance from base station in km [16].

Finally, the Bandwidth Utilization (B_U) is one of the important parameters that differentiates between SFR and the new hybrid FR methods; it shows how the total system bandwidth is utilized and it is defined as follows.

$$B_U = \frac{\text{BW per Cell}}{\text{Total System BW}} \quad (6)$$

Results

The seven cells' layout is the most commonly used model in cellular wireless network for the different applications including traffic management in ITS. The term ITS means exchanging information between the vehicles (mobile nodes or UEs) and the infrastructure (base station or eNB in LTE) by interconnecting them in one network [15]. Wireless communication, computing and sensing capabilities are added to the vehicle in order to allow communications from the vehicle to infrastructure [15,17]. The infrastructure sends all the necessary information regarding the traffic status of the surrounding environment to all vehicles in the coverage area. The vehicle collects this information and then determines the best way to the desired destination [17]. This means that any packet loss can affect the decision taken by the moving vehicle regarding the best way to the desired destination to avoid any traffic congestion (especially, if there is a lot of traffic exchanged between the mobile node and the infrastructure). Therefore, in this paper, the proposed new hybrid frequency reuse method is investigated in the context of traffic management application in ITS. Furthermore, the results are generalized by studying the simulated scenarios in different frequency bands. Fig. 4 shows the model studied in this paper that consists of seven cells; each cell contains one eNB with many fixed UEs around it and the seven eNBs are connected to one EPC. As mentioned before, the most important parameter measured in this paper is the packet loss. All simulations are run on OPNET and a 95% confidence analysis is carried out. The number of packets lost is in fact a random variable. Let it be called P. Let μ be the mean of this random variable and σ its standard deviation. Furthermore, let P_i be the number of packets lost in the ith OPNET simulation. If n OPNET simulations are run to obtain n samples of the number of packets lost, then $p = \frac{1}{n}\sum_1^n P_i$ is the sample mean and s^2 is the sample variance. p is a random variable that has its own distribution [18]. This distribution approaches the normal distribution irrespective of the original distribution of P. This is due to the Central Limit Theorem that also states that the mean of random variable p is μ and its variance is σ^2/n. Since p is normally distributed, the confidence interval can be calculated as the probability of p being within a certain distance of μ. Since σ^2 is difficult to obtain, s^2 can be used instead if $n > 30$ [18]; otherwise, the Student T distribution should be used instead of the Normal distribution. Consequently, 33 OPNET simulations will be run in this research in the confidence analysis [19]. The simulations using OPNET are done in the context of ITS applications with eight simulated scenarios according to four inter packet transmission times (IPTs) and two moving speeds. The IPTs are chosen based on a Manhattan map shown in Fig. 5 such that the eNB broadcasts the traffic information to the moving UEs every 30, 60, 90 or 120 s [20]. The two simulated speeds in this paper are 33 km/h and 60 km/h which represent the average and the maximum speeds in urban areas [19,20]. The inter-center distance between the adjacent eNBs equals 2.6 km according to 2.5 GHz frequency band and network parameters shown in Table 1 [2,16,20]. This distance is calculated using the OPNET simulator to find the optimum distance that minimizes the loss of data during the handover process. Each scenario of the eight scenarios is simulated using the two proposed frequency reuse methods and results are as follows.

Simulations results of SFR and the new hybrid FR method

All the simulated scenarios in this paper are investigated on a congested network as shown in Fig. 4. The congested model has 10 fixed UEs distributed randomly around each eNB and one moving UE similar to the scenarios studied in El-Dakroury et al. [20]. All UEs have the same traffic (same number of allocated PRBs). In the new method, the same simulated scenarios are used but the type of handover is changed from

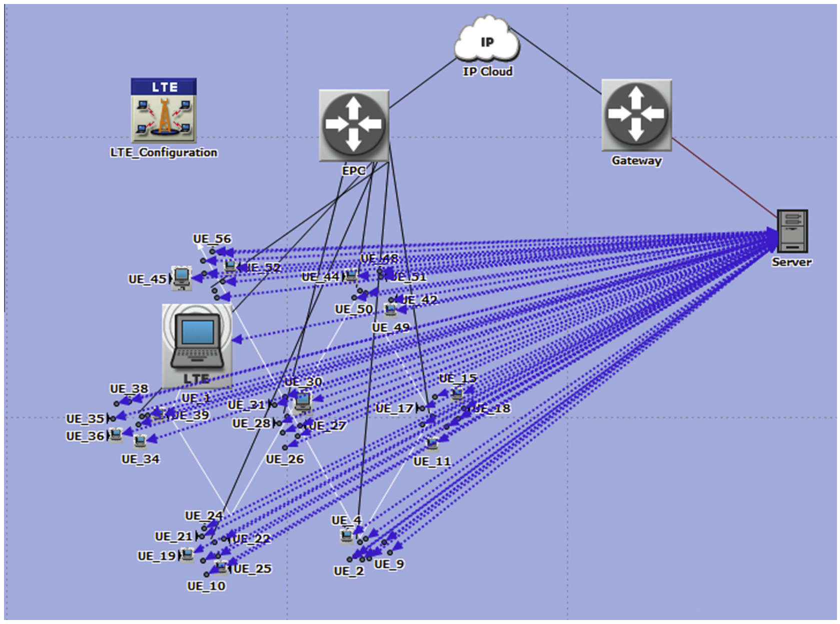

Fig. 4 The simulated model and the network architecture.

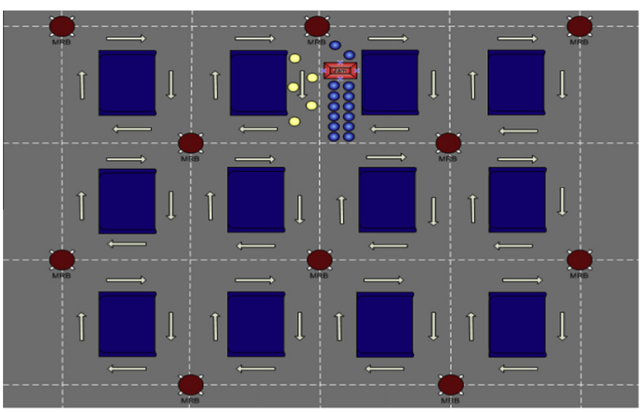

Fig. 5 The Manhattan map.

intrafrequency handover that is used in SFR to interfrequency handover due to the use of different center frequencies. Table 2 shows the mean value of the packet loss of the moving UE during the whole trajectory through the seven cells and the confidence interval using the SFR method and the new hybrid FR method. The values in the table indicate that the mean value of packet loss increased when decreasing the packets inter-arrival time. This is due to the increase in the number of transmitted packets which leads to an increase in the load on the LTE network and causes an increase in the packet loss. Also, it is noticed from the table that packet loss is increased by decreasing the speed and this is due to increasing the duration that the UE spends in the network. The table also shows the reduction in packet loss when using the new method and the values in the table show that the new hybrid FR method outperforms the SFR. This reduction is calculated as a mean value by subtracting the mean value of the new method from the mean value of the SFR; it is also calculated as a percentage from the mean value of the SFR.

Other measured parameters results

Although the packet loss is the main concern in this paper, there are some important parameters that are measured such

Table 2 Simulation results of SFR and new hybrid FR method (2.5 G*Hz* frequency band).

Speed Measured values	IPT = 30 s	IPT = 60 s	IPT = 90 s	IPT = 120 s
(SFR method) 33 m/h mean of packet loss confidence interval	1.79 (1.212, 2.424)	1.43 (0.997, 1.85)	0.76 (0.416, 1.099)	0.36 (0.125, 0.602)
(NHFR method) 33 km/h mean of packet loss confidence interval	1.66 (0.949, 2.38)	0.878 (0.454, 1.303)	0.63 (0.279, 0.87)	0.182 (0.023, 0.34)
Reduction (improvement) in packet loss due to the use of the new method (%)	0.13 (7.2%)	0.552 (38.6%)	0.13 (17.1%)	0.178 (49.4%)
(SFR method) 60 km/h mean of packet loss confidence interval	1.67 (1.109, 2.223)	0.6 (0.313, 0.9)	0.43 (0.2147, 0.6337)	0.212 (0.026, 0.398)
(NHFR method) 60 km/h mean of packet loss confidence interval	1.3 (0.674, 1.992)	0.6 (0.225, 0.987)	0.273 (0.096, 0.449)	0.06 (−0.022, 0.143)
Reduction (improvement) in packet loss due to the use of the new method (%)	0.3 7(22.1%)	0 (0%)	0.157 (36.5%)	0.152 (71.7%)

Table 3 The other measured statistics for SFR and the new FR method around 2.5 GHz frequency band.

The measured statistic	Simulations	
	SFR	New FR method
Handover delay	17.3 ms	13.7 ms
Path loss within the cell coverage	83 dB	83 dB
Path loss at the cell edge	130 dB	130 dB

as handover delay and path loss. These parameters are calculated using two methods. The first one uses the previous analytical equations and the second one uses OPNET simulations. According to the analysis and to Taha et al. [16], the maximum handover delay equals 65 ms, the path loss within the cell coverage equals 85 dB and the path loss at the cell edge equals 129 dB. According to the simulations, the average values are calculated and are shown in Table 3. The values in the table show that all the measured statistics for the proposed new hybrid frequency reuse method are within the allowable ranges that are mentioned in El-Dakroury et al. [20]. Regarding the bandwidth utilization (B_U), it is shown from Eq. (6) that the new hybrid FR has B_U less than SFR. The B_U for SFR equals 100% because of the use of the total system bandwidth per cell. But the new hybrid FR method has B_U around 66.7% (according to the used bandwidth) because part of the system bandwidth is used as a guard gap between carrier frequencies. These guard gaps are used to avoid the ICI and reduce the amount of packet loss which is very important in a lot of applications (such as traffic management in ITS) even more than the bandwidth utilization.

Packet loss in the other frequency bands

All the previous results are calculated around 2.5 GHz and it is noticed from the previous results that the new hybrid FR method outperforms the SFR with respect to the packet loss. Therefore, the results are generalized by examining the worst case scenarios (low speeds and low IPTs) at different frequency bands. The 1.92 GHz and 3.6 GHz are studied as the most commonly used TDD frequency bands [21]. The values in Table 4 show an increase in the mean value of packet loss when increasing the frequency band due to the reasons that are mentioned in Discussion next.

Discussion

All the previous results show that the mean value of the packet loss for the new hybrid FR method is better than the SFR method. This is because of the extra new sub-carriers that are provided by the new method due to the use of guard gaps between the different center frequencies for the neighbor eNBs. This leads to decreasing the ICI and consequently the packet loss is reduced. By investigating the same scenarios in the different frequency bands, the packet loss is increased with increasing the center frequency due to the high frequency attenuation, but the new method still outperforms the SFR method as noticed in Table 4. This guarantees that the new method can be generalized and the new provided sub-carriers do not differ according to the different frequency bands, but differ according to the used BW. In other words, for the same used bandwidth, all the different frequency bands will have the same number of new sub-carriers, which leads to decreasing the packet loss in the different frequency bands.

Regarding the other measured parameters such as handover delay and path loss, Table 4 shows the values that are obtained from OPNET simulations are very close to the analytical values. The handover delay is below the maximum analytical value for the SFR and the new hybrid FR method because the network is not overloaded. Regarding the path loss, it is calculated at the cell center by taking the parameter (R) at 100 m and it is calculated at the cell edge by taking R equal to the cell radius. It is found from calculations that the path loss for SFR and for the new method is the same and this is because the path loss parameter is more related to the environment than the frequency reuse method.

Conclusions

Long Term Evolution (LTE) is one of the most appealing fields of research due to its high performance with respect to the data rate, spectral efficiency, latency and large coverage. However, it suffers from ICI. Different methods are implemented to mitigate this type of interference. Frequency reuse methods are most commonly used in mobile communications such as SFR, HFR and FFR. Soft frequency reuse is used in this paper due to its high capacity and the simulation results show that this type of frequency reuse causes a noticeable loss of packets. Therefore, a new method of frequency reuse is implemented, in which the center frequency of each eNB is shifted by 25% of the used bandwidth from the neighboring eNBs. This proposed method gives some eNBs 25% (percentage from the used bandwidth) more new sub-carriers and other eNBs 50% more new sub-carriers. Consequently, this new method is investigated in the context of ITS applications and a reduction in the amount of packet loss is noticed compared to the SFR method. Furthermore, both frequency reuse methods are investigated in different frequency bands and the superiority of the new hybrid FR method is noticed and the improvement (reduction in packet loss) can reach 49.4% in some frequency bands.

Table 4 Mean values of the packet loss for the different frequency bands.

Speed/IPT	1920 MHz			3600 MHz		
	SFR method	NHFR method	Reduction in packet loss (%)	SFR method	NHFR method	Reduction in packet loss
33 km/h/30 s	1.75	1.6	0.15 (8.5%)	2.7	1.96	0.74 (27.4%)
33 km/h/60 s	0.8	0.636	0.164 (20.5%)	1.15	0.94	0.21 (18.2%)
60 km/h/30 s	1.424	0.94	0.484 (33.9%)	1.87	0.97	0.9 (48.1%)
60 km/h/ 60 s	0.75	0.57	0.18 (24%)	0.78	0.58	0.2 (25.6%)

Conflict of Interest

The authors have declared no conflict of interest.

Compliance with Ethics Requirements

This article does not contain any studies with human or animal subjects.

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