Interferences and Solutions in Long Term Evolution (LTE) Network: A Review

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***Abstract*—LTE is an enhanced of Universal Mobile Telecommunications Systems (UMTS) network, enriched with new and outstanding features geared towards its network and mobile users. Hence, it can improve poor network coverage and quality of service (QoS). Improper network designed by network operators and random deployments of femtocell behaviour will attract interferences and severely degraded the LTE network. This paper reviewed several interference management techniques to improve LTE network performances based on Third Generation Partnership Project (3GPP) in Rel-8 until Rel-12 from recent studies. This paper covers several interferences i.e. co-channel interference (CCI), cross-tier interference and inter-cell interference (ICI). The techniques reviewed focus on victim users e.g. at cell-edge and indoor areas in heterogeneous networks (HetNets). All techniques were explained and the variables used were reviewed.**

***Index Terms*—Cross-Tier Interference; Co-Channel Interference; Heterogeneous Network; Inter-Cell Interference; LTE.**

I. INTRODUCTION

LTE is a broadband wireless technology introduced in Rel-8 by 3GPP that aims to provide high data rate, low latency, greater spectral efficiency and a pure packet switched core network with scalable bandwidth capacity[1]. Malaysia is currently undergoing a transition in terms of the use of Third Generation (3G) cellular network to Fourth Generation (4G) technology because of its faster service, accommodates the use of high definition (HD) applications and has lower latency compare to 3G services. According to the report made by Ericsson, smart phones traffic growth is 11 times between the year 2015 to 2021 and 90% of future mobile data traffic originated from smart phones, [2]. As a result of such exponential growth in mobile data traffic, it is expected that LTE networks would also be overloaded in near future. LTE growing consumers will also cause some users to experience resource problems. This statement can be summarized as:

$$\text{Data traffic} \propto \frac{1}{Network\ Peformance} \quad (1)$$

In Equation (1), data traffic is inversely proportional to the performance in a network where it plays a major part in network performance. When data traffic is high at certain areas in a network e.g. hotspots, indoors and cell-edge areas, the network performance will decrease hence affect some users to experience drop calls. Network performance is closely related to the user satisfaction where if a network performance is poor, user satisfaction will decline. Thus it is essential for network operators to find a countermeasure so their subscribers will not switch to other competitors. One way to solve this issue is to add towers to underserved areas. According to [3], the inter-site distance of base stations (BSs) is assumed to be 500 meters, which is representative value of an interference-limited deployment. This method is not suitable for application due to construction cost of towers is excessive. Another alternative is the frequency reuse technique, which can be applied for network capacity improvement. With cost-of-service perspective in frequency reuse planning, it will maximize the number of users by using minimum number of BSs.

II. MANUSCRIPT PREPARATION LTE ARCHITECTURE AND FRAME STRUCTURE

LTE network consists of network of BSs or eNBs known as Evolved UTRAN (E-UTRAN) and the Evolved Packet Core (EPC). The eNBs are directly connected to each other through the X2 interface. LTE radio frame comprises of ten subframes with duration of 10 ms per frame. It adopts the 0.5 ms slot structure and uses the 2 slot allocation period where each subframe is 1 ms long. For every subframe, each slot consists of either 6 or 7 OFDM symbols and the first three OFDM symbols is use to control channels, while the latter OFDM symbols are used for the data channel. These control channels are used to inform the UEs of the scheduling assignments [4][5].

A well-known benefit of LTE is it supports low power nodes (LPNs) deployment i.e. femtocells, picocells, relay nodes and Wi-Fi access points (APs). Femtocell is a very small, short-range low-power BSs [6], user-deployed at homes or offices and also a cost effective wireless access points[7]. It was introduced in LTE Rel-10, which operate in licensed spectrum to connect small number of cellular users via Internet backhaul[6]. The femtocell can fills the coverage holes of macrocell network [7] by performing the resource assignation [1], reduced bandwidth load and fulfil power requirements. It also increased average revenue per user [8]and are used to enhance poor cellular coverage e.g. indoor areas. The typical indoor coverage of a femtocell is about ten meters[7]. Another LPNs, the picocell is deployed by the operator to improves coverage, capacity and better spectrum reuse in areas with high density of users (hotspots) [9]. Meanwhile, relay node does not require a dedicated backhaul network like the femtocell and picocells. It's function is to enhance coverage and increase capacity at poor coverage areas[4]. Other than that, Wireless Fidelity (Wi-Fi) technology is a cheaper wireless coverage extension and has widely deployed in houses or offices. However, Wi-Fi has short coverage and no guarantee of quality of service (QoS).

III. Interferences In LTE Network

Recently, there are a lot of past papers discussed about interference management regarding the deployment of LPNs in LTE HetNets e.g. multi-tier problems, power different problems and coexistence with unlicensed spectrum bands problems,[11] [12] [13]. LTE network only took consideration of inter-cell interference due to intra-cell interference can be neglected because LTE users are orthogonal [10]. There are two types of interferences in HetNets which are cross-tier and co-tier interference. Cross-tier interference occurs between macro and small cells when same bandwidth (resource block (RB)) is allocated for the UEs of both macro and small cell. Co-tier interference occurs when all small cells (also true for macro BSs) share the same spectrum resources through frequency reuse one, [16]. These issues may lead to network degradation if no countermeasures are taken by the network operators.

In order to mitigate these interferences, the 3GPP has introduced inter-cell interference coordination (ICIC) for LTE interference management in Rel-8. In general, the ICIC may be static or semi-static, with different varying levels of associated communication required between eNBs. The static ICIC is about cell planning and not using X2 interface. In contrast, the semi-static interference coordination is mainly about reconfigurations over X2 interface that obtains information between the BSs. It may be more suitable for cases of non-uniform load distributions in eNBs and varying cell sizes across the network, [14]. FFR is an example of static ICIC. It consists of two types: static FFR and adaptive FFR. The static FFR includes pre-planned frequency reuse type-1 (FR-1), frequency reuse type-3 (FR-3), or a mixture of both techniques. Two classis static FFR are: type-1 FFR and type-2 FFR. Adaptive FFR is an enhanced version of the static FFR by dynamically adapting it according to the channel quality measurements i.e. channel quality information (CQI) or the path loss of the users. Adaptive FFR has two classes which are partial frequency reuse (PFR) and soft frequency reuse (SFR). In Rel-10, the 3GPP introduced enhanced inter-cell interference coordination (eICIC) technique to deal with interferences in HetNets. The eICIC focuses on time-domain because they can accommodate downlink/uplink traffic asymmetry by varying the percentage of transmission time intervals (TTIs) for downlink and uplink transmission,[15]. Example of eICIC is Almost Blank Subframe (ABS) technique where this technique mutes some subframes to allow small cell to allocate its band hence interferences can be avoided. In Rel-11, the 3GPP introduced a coordinated multi-point (CoMP) technique to manage interference for LTE-advanced [17] and in Rel-12, interferences can be cancelled using device-to-device (D2D) communications technology, [18]. Other than the techniques mentioned above, power control is also a well-known technique to manage interferences. Unfortunately, this technique is not suitable to apply at HetNets due to the distance of user to small cell is in very small areas which are from 25 to 30m [1].

LTE network performances can be measured by several key items e.g. capacity and signal-to-noise ratio (SINR). The capacity of a network can be calculated using Shannon's formula as equation (2) where the rate of a single link can be increased by either choosing a higher transmission bandwidth or by levering the SINR.

$$Capacity = Bandwidth \times log_2(1 + SINR) \tag{2}$$

SINR value is derived from signal over interferences and noise as equation (3).

$$SINR = \frac{S}{(I + N)} \tag{3}$$

To achieve low SINR, the network operator can increase power of BS so the users at problematic areas can cancel out the interferences. Unfortunately, the technique is not suitable for heterogeneous network (HetNet) where the small cells are operating in low power.

This paper focuses on LTE interference management techniques at cell-edge areas, indoors and interference with other users or nodes or policies as mention in Section 4. All the techniques mentioned were compared in terms of different criteria and their variables or parameters usage as pointed in Section 5.

IV. Interference Management Techniques

A. *Fractional Frequency Reuse (FFR)*

The basic mechanism of FFR is dividing the cell into two regions and allocate it with different frequency reuse schemes to avoid adjacent interferences. C.Bouras *et.al* proposed FFR in LTE-femtocell network where each hexagonal cell of radius R were divided into inner and outer region in literature [6] as shows in Figure 1(a). The cell centre reuse factor of 1 while the rest of the spectrums were equally divided into three sub-bands and assigned to the cell edge users with reuse factor of 3. This technique achieved the highest User Satisfaction (US) compared to Integer Frequency Reuse (IFR) reuse-1 and IFR reuse-3. However, the simulation results of the proposed technique are not impressive for total cell throughput due to using the US as a metric where all the users are served with comparable quality. Comparing with it, P.Gao *et.al* proposed two frequency reuse pattern with certain distances which are the R_0 and R_{safe} to avoid overlapping of frequency reuse for the uplink and downlink spectrum between the macro and femto as shown in Figure 1(b), [8]. The proposed technique combines with spectrum sensing scheme for interference avoidance in LTE. However, the disadvantage of the proposed technique is its patterns are complex. In [20], H.Zhuang *et.al* recommended a similar method as above where the author splitted the spectrum into inner band and outer band as 3/1 reuse for cell-edge users and 1/1 universal reuse for cell-center users. The simulation results outperform the traditional scheme without the FFR. The advantages of this scheme are it can adapt to real dynamic traffic maps and reduce the operational cost. Nevertheless, this technique consume more time due to the genetic algorithm used in the scheme for mapping the traffic map. Other than that, D.Gonz *et.al* [21]and A. B. Patel *et.al* [12] proposed Soft Frequency Resource (SFR). D.Gonz *et.al* divided
the cell into interior and exterior area using the threshold value of SINR, S_{TH} as shows in Figure 1(c). The disadvantage of this technique is it focuses on macro

network only. In contrary, A. B. Patel *et.al* proposed using SFR for LTE-femtocell network by dividing a cell in two parts using SINR value 5 dB as reference as shows in Figure 1(d). Based on the results, capacity outperforms the traditional technique, however in terms of outage probability comparison, the proposed technique provide lower values than FR-1 technique but higher than FR-3.

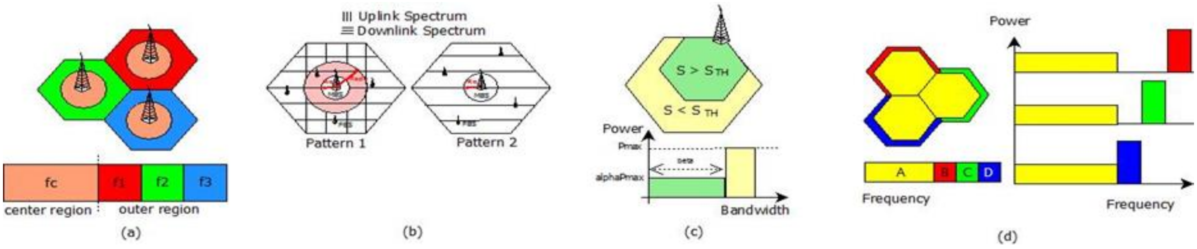

Figure 1: Proposed FFR and SFR patterns and its frequency and power allocation [6], [8], [21] and [12]

B. Almost Blank Subframe (ABS)

ABSs are subframes with reduced downlink transmission power or activity, intended to coordinate macro eNBs and small cells transmissions on heterogeneous deployments in such way that the small cells did not suffer severe interference during those silent periods. ABS has backward compatibility with LTE Rel-8 and Rel-9. In [22], E. Almeida et.al proposed a modified ABS for LTE-Wi-Fi coexistence network where it does not need the reference signals as shows in Figure 2(i). The Wi-Fi nodes will detect the low power at silent subframe and allocate its band to avoid interferences. This proposed technique will improved the performances achieved by users at Wi-Fi networks. The shortcoming of this technique is it focuses only in indoor environment. D. Lopez-Porez [23] proposed the ABS technique with additional improvement where the subframe splitted into two fragments (each of it will be RB/2) as shows in Figure 2(ii). Moreover, the splitted fragments is transmitted with different sector configuration i.e. 60 degrees and in the meantime, the small cell will see different signal qualities (SINR) in both spectrum fragments depending on the small cell locations. From the simulation results, the proposed technique will improve average throughput for users at macrocell and small cells. In addition, this also decreased the ABS duty. The drawback of this proposed technique is it only focuses for outdoor heterogeneous network especially for pico cells. In addition, R. Singh et.al [9] recommended a technique that utilizes protected subframe (PSF) at macro cell and pico cell as Figure 2(iii). The advantage of the proposed technique is the author use effective data rate as variable. From the results, the proposed scheme had improved in total capacity achieved by the system; while providing better signal-interference-to-noise ratio (SINR) to the victim users and improved the capacity achieved by MeNB victim users. The disadvantage of this proposed technique is it does not consider distance parameter.

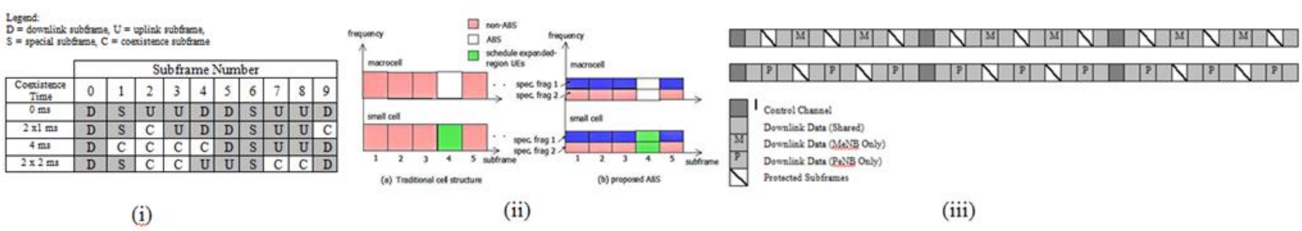

Figure 2: Proposed subframes pattern considering: (i) different times [22], (ii) splitted fragment [23] and (iii) PSF pattern [9]

C. Power Control

The basic mechanism of power control is focusing on avoiding small cells to transmit more power than the users required. In [1], M. Iturralde *et.al* proposed power control of femtocell using 2-person game bargaining between throughput and SINR at the femtocell in order to find an optimum trade-off between them to avoid interferences with its neighbours when the femtocell power level transmission is lower. The results show the proposed technique improved in throughput, Packet Loss Ratio (PLR) and SINR. The drawback of this technique is the interference value at macrocell is not taken into account in this literature. Moreover, A. Alexiou et.al [24] also proposed the power control technique. However, this techique uses priority grouping in which each user of femtocell was assigned to one of the available groups with different priorities in terms of power requirements and traffic load. But the advantages lies on it focuses on distance (between the access points (APs) and users parameter) and load as the parameters. However, the drawback of this method is it is more time consuming. In other research paper, F. S. Chaves et.al [25], proposed interference aware operating point in LTE-Wi-Fi network. The performance of this simulation network was measured by mean user throughput and results in improvement of Wi-Fi coexistence and slightly reduces in LTE network. The disadvantage of the proposed network is it focuses only at indoor network. However, in [26], K. Khawam et.al proposed power control technique focuses on outdoor areas. He used non-cooperative game where the interactions between players competing for a common resource. The advantages of the proposed technique are it can be controlled based on only local information and has low convergence time. The drawback its usage is only for macro network.

D. Resource Allocation

The basic mechanism behind resource allocation is blocking and denying access to the downlink resources which are subjected to greater co-tier and cross-tier interferences. In [19], A. Adouane et.al proposed an ICIC algorithm namely as replicator dynamics algorithm where it resulted in having the RBs that is not too highly interfered. The proposed technique was compared against Random algorithm and the results are quite attractive in terms of convergence time and total mean cost. However, the proposed method only focuses for the macro network. Comparing with it, V. Sathya in [16] proposed Variable Radius algorithm where it dynamically increases or decreases the radius of inner regions to avoid co-tier interference among Femto BSs only. The distance of this identified UE from the femtocell can be formulated as (4) where r is inner region radius and γ is the threshold distance.

$$r = (r + \gamma)/2 \quad (4)$$

E. Relays-Enhanced System

The basic mechanism of relays-enhanced system is it appears to relay UE (RUE) as macro BS and received all data from it when the RUE is near the relay. In [4], K. Ks et.al proposed a transparent relay-enhanced system for indoor premises due to it does not required dedicated backhaul network as femto and pico BSs and have CCI-suppressing capabilities. The simulations had been conducted to evaluate the proposed technique by comparing it to non-relay system and the results achieved is quite attractive where there is an improvement in mean throughput of the network. However, the proposed technique has disadvantage where it needs a large number of relays which consists of 140 relays across 21 sectors.

F. Device-to-Device (D2D)

The basic mechanism of the device-to-device (D2D) scheme is operator-controlled with the possibility of tight control of D2D resources to manage ICI for victim users. In [18], R. Tanbourgi et.al discussed challenges and proposed cooperative interference cancellation technique using D2D communication in three possible deployment which are intra-cell D2D cooperation, inter-cell D2D cooperation and one-way D2D cooperation. The advantage of this technique is it was not tied to a backhaul. However, it may decays much slower with distance due to the cell-association mechanism.

V. COMPARISON

All techniques discussed above can be categorized in several aspects such as types of interferences, variables, access mode, algorithm used and the degree of complexity. Based on the analysis, it is shown that FFR technique can be used to mitigate the adjacent interference, ABS and relay-enhanced techniques can be applied to reject co –channel interference, D2D technique can suppress inter-cell interference and power control while resource allocation techniques are use to mitigate co-tier and cross-tier interference in LTE HetNets. To improve the network performance for system-level network, power, distance and path loss are variables that have been applied to the techniques discussed in the paper. For the physical layer or link-level system, data rate was used as variable to enhance the link performance. In term of complexity, relay-enhanced system is very complex compared to other techniques because it needs a high number of relays in a sector and it operates in closed access mode. Other than that, proposed algorithm for power control and resource allocation is decentralized algorithm where the BSs optimize their local parameters without central controllers. It can adapt to fast change of network state though it is difficult to avoid converging to local optimum, [19]. Table 1 shows a brief comparison of different interference mitigation techniques discussed in the paper.

Table 1
Comparison table of different mitigation schemes

Topic	Techniques					
	FFR	ABS	Power Control	Resource Allocation	Relay	D2D
Interference	Adjacent	CCI	Co-tier/ Cross-Tier	Co-tier/Cross-Tier	CCI	ICI
Variables	-	Data Rate	Power	Distance	Path Loss	-
Complexity	Medium	Medium	Medium	Medium	High	Medium
Access mode	-	-	-	-	Closed	-
Algorithm type	-	-	Decentralized	Decentralized	-	-

VI. CONCLUSION

Interference is a crucial matter which needs to be studied on how to overcome it in order to avoid degradation in LTE network. There are several methods in recent studies that may be apply for managing interferences such as FFR, ABS, power control, resource allocation, relay-enhanced system and D2D techniques. In conclusion, network operators must design interference management wisely with cost-effective and network friendly solutions. From the techniques researched in this paper, there are many techniques that can be applied for interference management such as at physical layer in OFDM, cell planning, using small cells instead BSs, schedulers and others. The variables used in the literatures are also important for studies that are using RSRP, bitrate, distance and others.

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