TESIS – TE142599

RESOURCE ALLOCATION IN LTE-A NETWORK FOR MACHINE TYPE COMMUNICATIONS (MTC) OVER WI-FI SPECTRUM UNDER LAA FRAMEWORK

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APPROVAL SHEET

Thesis has been done to satisfy one of the requirements to obtain the degree of
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THESIS AUTHENTICATION FORM

I hereby state that the contents in part of overall my thesis entitled **"Resource Allocation in LTE-A Network for Machine Type Communications (MTC) over Wi-Fi Spectrum under LAA Framework"** is actually the work of intellectual standalone, solved without using forbidden materials and not the work of others that I admit as my own work. All cited references have been written in the bibliography. If this statement is not true, I am willing to receive sanctions as provided by law.

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ABSTRACT

Heterogeneous Network (HetNet) is a combination networks such as macro cell and small cell introduced as LTE-A standard in 3GPP Release 10 to provide higher network capacity and coverage. In multilayer network, macro cell may has much higher transmit power than small cell, and causes small cell users suffer interference with macro cell. The cell-edge users of small cell may use the same radio resources with macro cell users. To cope this interference problem, We propose optimization for resource allocation using Taguchi's method in scheduling users to achieve higher LTE-A system throughput. Resource allocation has an important part in influencing the communication networks performance to reduces inter-cell interference and improves the system's throughput.

Machine to Machine Communication (M2M) or known as Machine Type Communication (MTC) is a future wireless communication technology will be carried for industry 4.0. In HetNet, we consider some networks such as small cell, macro cell, Wi-Fi and MTC or IoT devices operate in different bands, licensed and unlicensed. Macro cell as the primary cell, while small cell as the secondary cell. 3GPP allows some networks coexistence in the unlicensed band using Listen Before Talk (LBT) access mechanism. We consider FBE-based LBT to possible coexistence among LTE-LAA users, Wi-Fi and IoT devices in our simulation. Through matlab-based simulation, we evaluate the LTE-A system throughput performance of different frequency band and environment, and also compare with other optimization algorithm, such as Genetic Algorithm. As the result, Proportional Fair (PF) is an appropriate scheduler to be used both in licensed and unlicensed than Round Robin (RR) and Blind Equal Throughput (BET) because it achieves higher throughput than other scheduler. We also observed that system throughput of unlicensed band is higher than licensed band.

Key words: LTE-LAA, Machine Type Communication, interference, FBE-based LBT, resource allocation

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Taipei, 17 July 2018

Rosabella Ika Yuanita

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CHAPTER 1
INTRODUCTION

Machine-to-Machine (M2M) communications, or well known as Machine Type Communications (MTC) will be the future wireless communication technology used for industry 4.0 application. 3GPP provides MTC services in LTE network. It has different characteristics from Human Type Communications (HTC), such as small and infrequent data transmission. In 2020, it is predicted become massively number about 50 billion IoT devices (IoTD) connected to mobile devices in the worldwide [1]. MTC does not require human intervention when transfer its data. Several prevalent IoTD for wireless factory automation systems such as Raspberry Pi 3, Arduino UNO and Waspmote are equipped with Wi-Fi radios [2].

Contemplate on the bursty of subscriber number in LTE-A network affected on the traffic demand, it should be one key challenge for network operator to increase network capacity in fulfilling the requirement of cellular users without degrading the quality of service (QoS). One of the solutions for network capacity enhancement aside of adding a number of base station is carrier aggregation (CA). 3GPP has developed CA in LTE-A network that provide larger bandwidth system by combining the unlicensed spectrum and licensed spectrum in the downlink using Listen-before-talk (LBT) protocol. This technology namely as licensed assisted access (LAA). As we know, LAA is different from LTE-U (LTE in Unlicensed Spectrum). In LTE-U which was developed by 3GPP Rel. 10, does not mandate implementing LBT protocol. LTE-U would allow cellular carriers to boost coverage in their cellular networks, by using unlicensed band has been populated by Wi-Fi devices.

There are several serving cells consist of primary and secondary serving cell when the component carriers are used on different frequency bands will be experienced in different both of coverage and pathloss. As seen in the Fig. 1.1, there is different type of cells in the network, such as small cells within macro cell coverage. It called as heterogeneous networks (HetNet). Refers to 3GPP Release 10, HetNet environment is also considered as LTE-A standards. In a homogeneous network, this is not a big problem because there isn't much difference in Transmit power (Tx) from neighbor cell's antenna, and hence no significant inter-channel interference by control channels is caused between neighbor cells at cell edge. On the other hand, in HetNet where a macro cell has much higher Tx power than a small cell, the small cell's control channel is inevitably interfered with by the macro cell. The cell-edge UEs in small cells from being interfered with by the neighboring macro cell by having both cells still use the same radio resources, but in different time ranges (subframes). To cope its problem, we propose optimization for resource allocation using Taguchi's method in allocating channel to users to achieve higher LTE user throughput. Resource allocation has an important part in influencing the communication networks performance to maintain QoS and handle to reduce inter cell interference. On the other side, a feasibility study of [3] recommended to LTE operator to change scheduling mechanisms to maintain the QoS both of HTC and MTC.

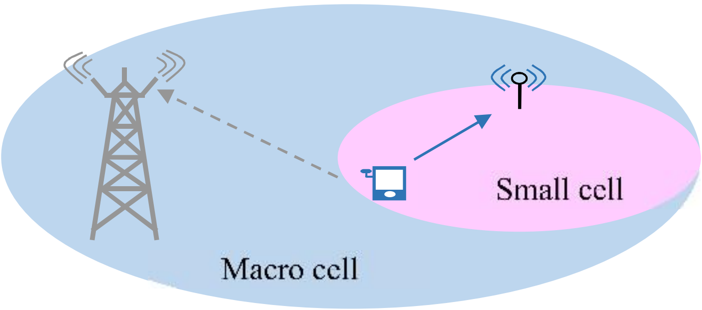

Figure 1.1 The cell-edge UE in heterogeneous network has inter cell interference

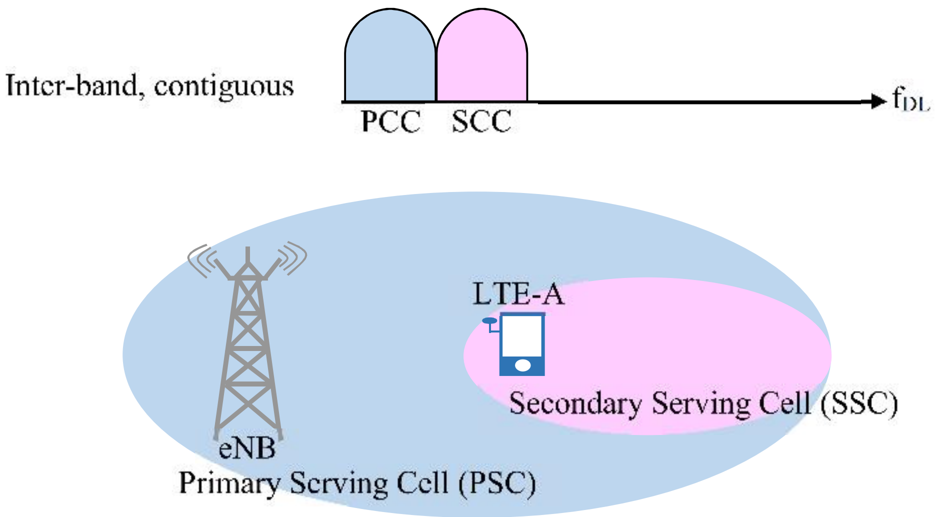

Figure 1.2 LAA deployment scenario

The IoTD sharing the channel together with Wi-Fi users during idle period and follow the 802.11 CSMA/CA protocol. IoTD have to defer their access until the LTE data blocks finishes [2]. The existence both of Wi-Fi and IoTD under LAA framework can give the influence on LTE network throughput. Therefore, the optimization for resource allocation being important to investigate. But, in some references [4-6] did not consider the effect of IoTD under LAA framework. Hence, in this research, we consider the impact of coexistence between Wi-Fi and IoTD in the unlicensed spectrum and compare the result of Taguchi's method to other optimization algorithms, such as GA (Genetic Algorithm). Take into consideration for factory environment, we develop the LAA deployment scenario refer to scenario 1 in 3GPP Rel. 13 as represented in Figure 1.2, where macro cell denoted by Primary Serving Cell (PSC) behaves as control management to provide the connection, while small cell denoted by Secondary Serving Cell (SSC) enroll as booster cell to provide higher throughput. In this case, we use inter-band and contiguous for carrier aggregation configuration, the primary component carrier is 2 GHz and secondary component carrier is 5.2 GHz. In this LAA scenario, carrier aggregation is between non-co-located cells which mainly motivated by hotspot scenario.

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CHAPTER 2
THEORETICAL BACKGROUND

3.1 LTE-LAA (Licensed Assisted Access)

LTE-LAA is a standardized version of LTE-U (Unlicensed) governed by 3GPP Rel 13 works by enlarge a carrier's LTE service by utilizing the unlicensed spectrum in the frequency range of 5 GHz ISM (Industrial, Scientific and Medical) band. The carrier augmentation regulates transmission power limitations, and protocols such as Clear Channel Assessment (CCA) and Listen-Before-Talk (LBT) when try to access the channel. Cellular carriers will use LTE in the licensed band for their anchor service and will augment the service with unlicensed spectrum via small cells. However, unlicensed spectrum significantly increases network capacity and coverage, both in crowded public indoor in outdoor areas such as stadiums and malls, also produces better spectrum efficiency than Wi-Fi, that leads to the higher data rates and capacity. The key difference between LTE-U and LTE-LAA is LTE-U requires dynamic channel selection and adaptive duty cycle/CSAT to mitigate collisions, while LAA requires LBT to comply with global coexistence standards with Wi-Fi [7].

One approach of LTE-LAA is to use unlicensed spectrum alongside the licensed bands, called ISM band are allocated in different parts of the spectrum and are used for a wide variety of applications including microwave ovens, Wi-Fi, Bluetooth, and much more. Here as seen in the Figure 2.1,

Figure 2.1 5 GHz bands for LTE-U / LTE-LAA [7]

there are several hundred MHz of spectrum bandwidth available, although the exact bands available depend upon the country. In certain markets such as the United States, South Korea, and India, a protocol called Listen-Before-Talk (LBT) that was designed to ensure fair coexistence.

The use of 5 GHz bands for LTE-U or LTE-LAA needs some regulatory requirements to access those frequencies that of coexist with other users, such as Clear Channel Assessment (CCA), or Listen Before Talk (LBT). Not to speak of, requires different power levels allowed dependent upon the country and the area of the band being used. Particularly, a maximum power limit between 5150 and 5350 MHz is 200 mW can be operated for indoor use only, whereas, the upper frequencies often allow power levels up to 1 W. Essentially, user equipment enables use more than one channel, either in the same or different band through carrier aggregation capability of LTE-Advanced.

2.1.1 Carrier Aggregation

LTE-LAA operates LTE-CA (Carrier Aggregation) compounds between FDD and TDD. This provides much greater flexibility levels to select the band to be used with in unlicensed spectrum. With carrier aggregation, end users should experience better performance as service quality is ensured if unlicensed band becomes unstable due to interference. Each aggregated carrier is referred to as a component carrier, CC. The component carrier can have a bandwidth of 1.4, 3, 5, 10, 15 or 20 MHz and a maximum of five component carriers can be aggregated, hence the maximum aggregated bandwidth is 100 MHz [8-9]. In FDD the number of aggregated carriers can be different in DL and UL. However, the number of UL component carriers is always equal to or lower than the number of DL component carriers. The individual component carriers can also be of different bandwidths. For TDD the number of CCs as well as the bandwidths of each CC will normally be the same for DL and UL.

The easiest way to arrange aggregation would be to use contiguous component carriers within the same operating frequency band (as defined for LTE), so called intra-band contiguous. This might not always be possible, due to operator frequency allocation scenarios. For non-contiguous allocation it could either be intra-band, i.e. the component carriers belong to the same operating frequency band, but have a gap, or gaps, in between, or it could be inter-band, in which case the component carriers belong to different operating frequency bands as seen in Figure 2.2.

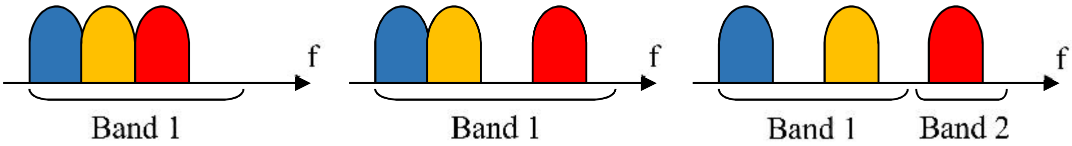


Figure 2.2 Carrier Aggregation in 3GPP: (a) Intra-band, contiguous; (b) Intra-band, non-contiguous; (c) Inter-band, non-contiguous [8-9]

2.2 Inter-Network Coexistence

The networks coexistence should be well designed to enhance the fair coexistence between LTE-LAA, Wi-Fi and IoT networks in LAA framework. LTE-LAA possesses a high flexibility for resource allocation and doesn't use carrier sensing mechanism, meanwhile, Wi-Fi STA and IoT devices require energy detection before transmission. Wi-Fi system adopts CSMA/CA mechanism to access the channel, IoT devices can either uses LBT-based mechanism or CSMA/CA. They will 'freeze' their DCF processes during Channel Occupancy Time. IoT devices will receive their single new packets during Channel Occupancy Period and have been programmed to wait at a random time from the end of the LTE block transmission are selected uniformly over [0, IdlePeriod). If IoT devices and Wi-Fi STAs use the same protocol, say, CSMA/CA access mechanism, it will be considered to the different possible DCF (back-off stage, back-off counter) combinations through the Fixed Frame Period (FFP). Both IoT devices and Wi-Fi return to the idle state when the transmission is done, or packet times out. The detail process of access mechanisms are presented in the following :

2.2.1 Listen before Talk (LBT)-Based LTE-LAA Mechanism

LBT is an access mechanism for LTE-Licensed Assisted Access (LAA) to support fair coexistence with other nodes and Radio Access Technologies (RATs), such as Wi-Fi as a part of LTE Advanced in 3GPP Release 13. This access mechanism proposes lower interference and minimize collision probability when two or more nodes are contending the channel at the same time. It uses carrier aggregation in the downlink to combine LTE in unlicensed spectrum (5 GHz) with LTE in the licensed band. This aggregation provides faster data rates and more responsive user experience. According to [10], ETSI proposes two channel access mechanisms, there are :

a) Frame Based Equipment (FBE)

In FBE-based LBT schemes, equipments should perform Clear Channel Access (CCA) before starting their transmission to sense whether the channel is occupied or idle using energy detection for a time equivalent to $\geq 20\ \mu s$. If the channel is idle, the predefined threshold energy value is considered to be higher than that of the channel, hence it can immediately initiate its data transmission for a period equal to 5% of Channel Occupancy Time (COT). However, if there is an equipment occupies the channel, it should be waiting for the next FFP and there will be no transmission during current FFP. The duration that channel can be occupied by equipments as mentioned as COT is fixed from 1 ms and should not exceed 10 ms. FBE allows to perform CCA only once for every Fixed Frame Period (FFP). At the end of an idle period, FBE performs CCA again and another equipment can occupy the channel if the channel is sensed to be free. Figure 2.3 shows FBE-based LBT access mechanism

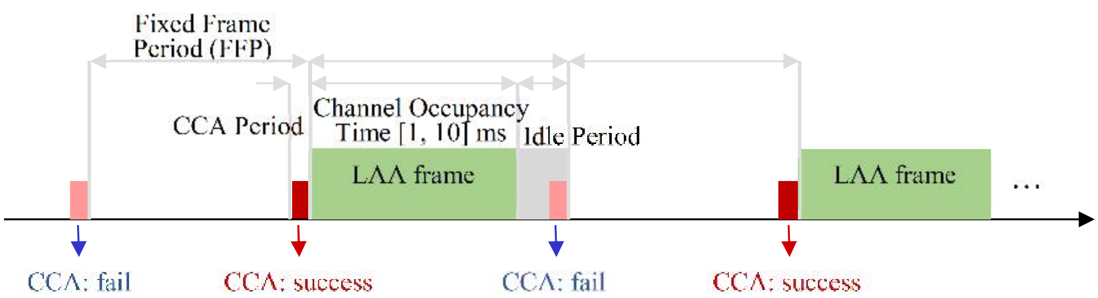


Figure 2.3 FBE-based LBT access mechanism

b) Load Based Equipment (LBE)

LBE access mechanism is similar to CSMA access mechanism of Wi-Fi, but, it does not apply exponential. It adopts fixed linear back-off with fixed size of contention window (CW) depends on the selected uniform back-off counter N, which keeps channel access opportunities of Wi-Fi still very low when channels are over-loaded. For this reason, 3GPP LAA is trying to make window size range in LBE variable in its LBT standardization effort. Similar to FBE, LBE also performs CCA whenever there is equipment needs to do data transmission. If the channel is clear, data is transmitted immediately. But, if occupied, it attempts to transmit after back-off during the extended CCA (ECCA). The principle of LBE can be explained in Figure 2.4.

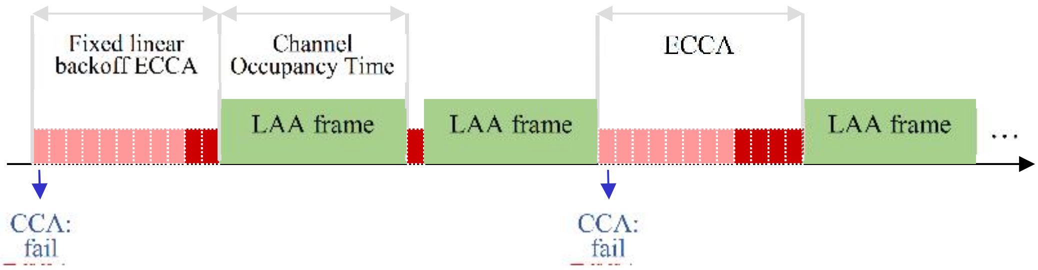


Figure 2.4 LBE-based LBT access mechanism

2.2.2 CSMA/CA Back-off Mechanism

CSMA or Carrier Sense Multiple Access/Collision Avoidance is a network contention protocol used for carrier transmission in networks using the 802.11 standard to reduces collision. Wi-Fi system is a technology uses 802.11 standard. Stations (STAs) and Access Points (APs) use Distributed Coordinated Function (DCF) to control, management frames and exchange data. DCF adopts CSMA/CA mechanism with CW-based protocol, such that before initiate any transmission, nodes should sense the channel to detect energy level. All nodes, including 802.11 standard-based node should perform CCA to know the channel status. The procedure of CCA for CSMA/CA mechanism has the same way as LBT-based mechanism.

Initially, if a channel is idle for the shortest CCA and idle for DIFS, STA can transmit immediately, otherwise, STA draws a pre-defined uniform random back-off number N from a certain range [0, CWmin−1], where CWmin is the minimum CW in the range of 15 time slots to the maximum CW, CWmax) of 1023 time slots. And when the channel is sensed to be free, the counter will be exponentially decremented and deferred if sensed to be busy until the channel is declared as unoccupied. Such that process will be repeated until the channel is sensed to be idle again for more than a DIFS period and the transmission is initiated once the back-off counter reaches zero. The successful transmission will be received Acknowledgment (ACK), while the transmission is failed, CW is double until the maximum value is reached for the next back-off stage, then a new random back-off number is selected. Back-off number is generated by follows the binary exponential distribution. If the transmission did not successful yet up to retry limit, the data frame will be dropped. All 802.11 standard-based protocol in 5 GHz band is controlled by inter-frame space (IFS) between transmission of frames, and the length of the slot time, Short Interframe Space (SIFS) and DCF Interframe Space (DIFS) are set to be 9 μs, 16 μs and 34 μs respectively. Slot time is needed for station to sense end of frame, start transmitting and beginning of frame to propagate to others. SIFS is time for station to sense end of frame and start to transmit. DIFS is required to wait before starting back-off interval is equal to SIFS + 2 x Slot Time. DCF process is explained in Figure 2.5.

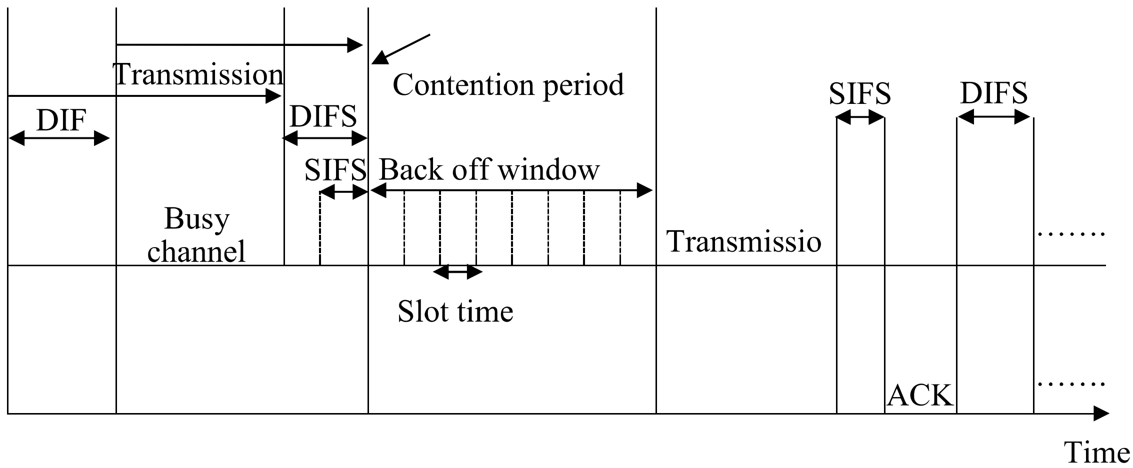


Figure 2.5 DCF Process

2.2.3 Downlink (DL) LAA Categories

According to 3GPP Rel. 13, there are 4 categories of DL LAA :

1. *Category 1: No LBT.*
2. *Category 2: LBT without random back-off. (e.g. ETSI Frame Based Equipment).*

The duration of time that the channel is sensed to be idle before the transmitting entity transmits is deterministic.

3. *Category 3: LBT with random back-off with a fixed contention window size. (e.g. ETSI Load Based Equipment).*

   The transmitting entity draws a random number N within a contention window. The size of the contention window is specified by the minimum and maximum value of N. The size of the contention window is fixed.

4. *Category 4: LBT with random back-off with a variable contention window size.*

   The transmitting entity draws a random number N within a contention window. The size of contention window is specified by the minimum and maximum value of N. The transmitting entity can vary the size of the contention window when drawing the random number N.

2.3 Optimization Algorithm

2.3.1 Taguchi's Method

In general, experiments are used to learn the systems or processes performance. Researcher may examines all parameter combinations, which is called a full factorial experiment to study the optimum result. However, it will spend much cost, both time and money and run too many trials in practice. Hence, Taguchi's approach is an alternative method with only a few experimental runs to obtain optimal result.

Taguchi's method is orthogonal arrays (OAs)-based optimization algorithm consists of system design, parameter design and tolerance design procedures to improve the product quality. To achieve the best result, the experiment should be strategically designed which discloses the process to various levels of design parameters. Taguchi's approach specified three situations, there are the larger the better (for example, agricultural yield); the smaller the better (for example, carbon dioxide emissions); and on-target, minimum-variation (for example, a mating part in an assembly). It used Signal-Noise (S/N) ratio as measurable value instead of standard deviation to know the quality characteristic of choice.

OA has a structure equal to OA(N, k, s, t). For instance as explained in Table 2.1, OA(27, 10, 3, 2), which has 27 rows and 10 columns. Each entry of the array is selected from a set S = {1, 2, 3}. Thus, this is a three-level OA. Pick any arbitrary two columns (t = 2) and one may see nine possible combinations as a row: (1, 1), (1, 2), (1, 3), (2, 1), (2, 2), (2, 3), (3, 1), (3, 2), (3, 3). It can be simply verified that each combination has the same number of occurrences as a row, i.e., three times. This is the meaning of "orthogonal" in the definition, which ensures a balanced and fair selection of parameters in all possible combinations. When this OA is used to design experiments, the 10 columns represent 10 parameters that need to be optimized. For each column, the entries 1, 2, and 3 denote three specific statuses or levels that an optimization parameter may select from. Note that for different optimization parameters, the levels 1, 2, and 3 may correspond to different numerical values. Therefore, the corresponding values for the levels depend on the parameters and vary in different applications.

Tabel 2.1 The OA(27, 10, 3, 2) [11]

Experiments	**Elements**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1	1	1	1	1	1	1	1	1	1
2	2	1	2	2	2	3	3	1	2	3
3	3	1	3	3	3	2	2	1	3	2
⋮	⋮									
25	1	3	3	3	2	2	1	3	2	3
26	2	3	1	1	3	1	3	3	3	2
27	3	3	2	2	1	3	2	3	1	1

Each row of the OA describes a certain combination of the levels for these 10 parameters. For example, the first row means that all parameters take the level 1. The second row means that arrays parameters 2 and 8 take level 1; parameters 1, 3, 4, 5, and 9 take level 2; and parameters 6, 7, and 10 take level 3. Once each parameter is assigned to a corresponding level value, one can conduct the experiment and find the output result. It is important to point out that the 27 rows of the OA indicate that 27 experiments need to be carried out per design iteration.

2.3.2 Genetic Algorithm (GA)

Genetic algorithm is a random-based classical evolutionary algorithm according to Darwin's theory. The meaning of random here is random changes applied to the current solutions to generate new ones. GA works on a population consists of some solutions where the population size represents the number of solutions. Each solution is called individual chromosome. A chromosome has a set of genes with different fitness value which represented as a set of parameters (features) that defines the individual. Fitness value is used to know the quality of the solution, then select the best individual. If the purpose is to maximize the value, the higher fitness value the higher the quality of the solution, and vice versa. Selection of the best individuals based on their quality is applied to generate what is called a mating pool where the higher quality individual has higher probability of being selected in the mating pool.

The individuals in the mating pool are called parents. Every two parents selected from the mating pool will generate two offspring (children). By just mating high-quality individuals, it is expected to get a better quality offspring than its parents. This will kill the bad individuals from generating more bad individuals. By keeping selecting and mating high-quality individuals, there will be higher chances to just keep good properties of the individuals and leave out bad ones. Finally, this will end up with the desired optimal or acceptable solution. The most important procedures of GA are the chromosome encoding, evaluation, and GA operators such as selection, crossover and mutation, and the last is termination condition. Each procedure will be explained in the following :

1. Chromosome Encoding

Chromosome encoding represents transformation of solved problem in GA to N-dimensional space of real (integer) numbers (mostly). It is important for problem solution to select proper encoding. Various encodings are discussed below:

- **Binary**

Binary encoding is the most common used in GA. Every chromosome consists of a string of bits, 0 or 1. But, this type of encoding is often not natural for some problems and need some corrections after perform crossover and/or mutation.

1	1	0	0	1	1	0	0	1	0

Figure 2.6 The example of binary encoding

- **Permutation: Traveling Salesman Problem, The Eight Queens Problem**

Permutation encoding can be used in ordering problems, such as travelling salesman problem or task ordering problem. In permutation encoding, every chromosome is a string of numbers, which represents number in a sequence. Permutation encoding is only useful for ordering problems. Even for this problems for some types of crossover and mutation corrections must be made to leave the chromosome consistent (i.e. have real sequence in it). In this following is some examples of permutation encoding, including :

a) **Travelling salesman problem**

There are cities and given distances between them. Traveling salesman has to visit all of them, but he does not want to travel more than necessary. Find a sequence of cities with a minimal traveled distance. Here, encoded chromosomes describe the order of cities the salesman visits.

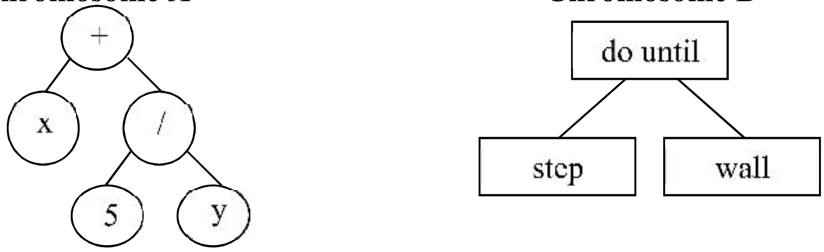
b) **The eight queens problem**

There are eight queens. Find a way to place them on a chess board so that no two queens attack each other. Here, encoding describes the position of a queen on each row.

- **Permutation: Traveling Salesman Problem, The Eight Queens Problem**

Tree encoding is used mainly for evolving programs or expressions, for genetic

Chromosome A **Chromosome B**



(+ x (/ 5 y)) **(do until step wall)**

Figure 2.7 The example of tree encoding

programming. In tree encoding every chromosome is a tree of some objects, such as functions or commands in programming language. Tree encoding is good for evolving programs.

- **Value Encoding**

Every chromosome in value encoding consist either of real numbers, integer numbers, characters or objects. It can be used in some problems, but it is often required to develop some new types of crossovers and mutations.

Chromosome A	1.2324	5.3243	0.4556	2.3293	2.4545
Chromosome B	ABDJEIFJDHDIER				
Chromosome C	(back), (back), (right), (forward), (left)				

Figure 2.8 The example of value encoding

2. Evaluation

Evaluation phase is the next step after chromosome encoding. This step in GA is used for measure the quality of each individual and allows to distinguish among good and bad individuals. This phase can be processed by calculate its fitness value of a chromosome. The equality of the fitness value also can be differentiated by its purpose, either maximize or minimize. If we want to maximize the value, so we should use $f = h$ as a fitness equality, but if we want to minimize the value, it should be denoted as the inversion off, or can be written as $f = 1 / h$.

3. Genetic Operators

Genetic operators are used to maintain genetic diversity. Genetic diversity is a necessary for the evaluation process. There are three main kinds of genetic operators, such as selection, crossover and mutation.

- **Selection Methods**

Next is to select a number of individuals from the population in the mating pool. Based on the selected individuals in the mating pool, parents are selected for mating. The selection of each two parents may be by selecting parents sequentially (1-2, 3-4, and so on). Another way is random selection of the parents. As mentioned before, six different selection methods are considered in this work, namely: roulette wheel, stochastic universal sampling, rank-based, and tournament selection. In this section, a brief description of each studied selection method is provided.

a) Roulette Wheel Selection (Fitness-Proportionate Selection)

The conspicuous characteristic of this selection method is the fact that it gives to each individual *i* of the current population a probability *p*(i) of being selected, proportional to its fitness *f*(i). In a roulette wheel selection, the circular wheel is divided as described before. A fixed point is chosen on the wheel circumference as shown and the wheel is rotated. The region of the wheel which comes in front of the fixed point is chosen as the parent. For the second parent, the same process is repeated.

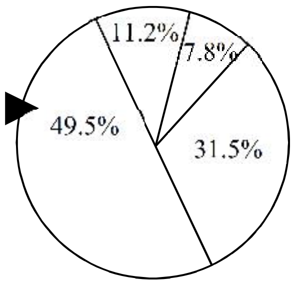


Figure 2.9 The example of Roulette-Wheel selection

From the above figure, it is clear that a fitter individual has a greater pie on the wheel and therefore a greater chance of landing in front of the fixed point when the wheel is rotated. Therefore, the probability of choosing an individual depends directly on its fitness.

b) Stochastic Universal Sampling (SUS)

Stochastic Universal Sampling is quite similar to Roulette wheel selection,

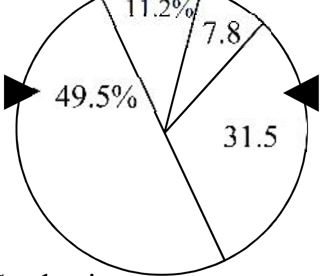


Figure 2.10 The example of SUS selection

however instead of having just one fixed point, it has multiple fixed points as shown in the figure 2.10. Therefore, all the parents are chosen in just one spin of the wheel. Also, such a setup encourages the highly fit individuals to be chosen at least once. It is to be noted that fitness proportionate selection methods don't work for cases where the fitness can take a negative value.

c) Rank-based Selection

In this method, every individual in the population is ranked according to their fitness. The selection of the parents depends on the rank of each individual and not the fitness. The higher ranked individuals are preferred more than the lower ranked ones. Rank Selection also works with negative fitness values and is mostly used when the individuals in the population have very close fitness values (this happens usually at the end of the run).

Tabel 2.2 The example of rank-based selection

Chromosome	Fitness Value	Rank
A	8.1	1
B	8.0	4
C	8.05	2
D	7.95	6
E	8.02	3
F	7.99	5

This leads to each individual having an almost equal share of the pie (like in case of fitness proportionate selection) as shown in the following image and hence each individual no matter how fit relative to each other has an approximately same probability of getting selected as a parent. This in turn leads to a loss in the selection pressure towards fitter individuals, making the GA to make poor parent selections in such situations.

d) Tournament Selection

In K-Way tournament selection, we select K individuals from the population at random and select the best out of these to become a parent. The same process is repeated for selecting the next parent. Tournament Selection is also extremely popular in literature as it can even work with negative fitness values.

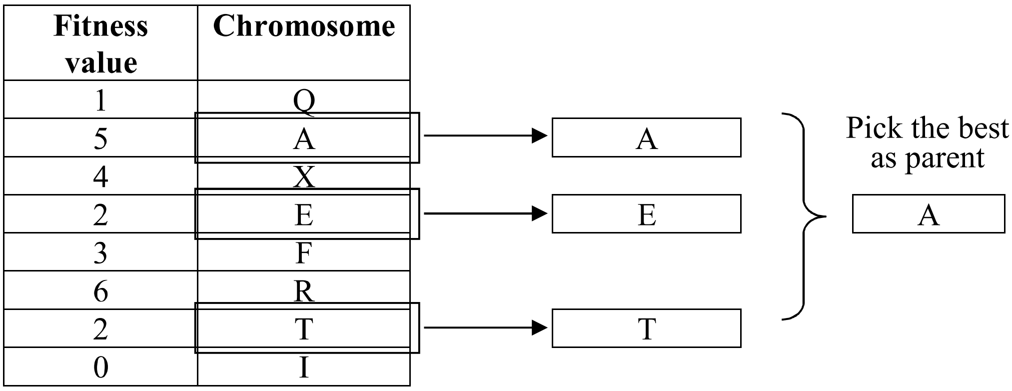


Figure 2.11 The example of Tournament selection

- **Crossover (Recombination)**

Crossover in GA generates new generation the same as natural mutation. By mutating the old generation parents, the new generation offspring comes by carrying genes from both parents. The amount of genes carried from each parent is random. Remember that GA is random-based EA. Sometimes the offspring takes half of its genes from one parent and the other half from the other parent and sometimes such percent changes. For every two parents, crossover takes place by selecting a random point in the chromosome and exchanging genes before and after such point from its parents. The resulting chromosomes are offspring. Thus, operator is called single-point crossover. Without crossover, the offspring will be identical to its parent.

a) One Point Crossover

One-Point crossover is the simplest method by randomly select one point and combines two genes from parents to create two new child chromosomes (offsprings). This crossover interchanges parent chromosomes after the crossover points looks as shown below :

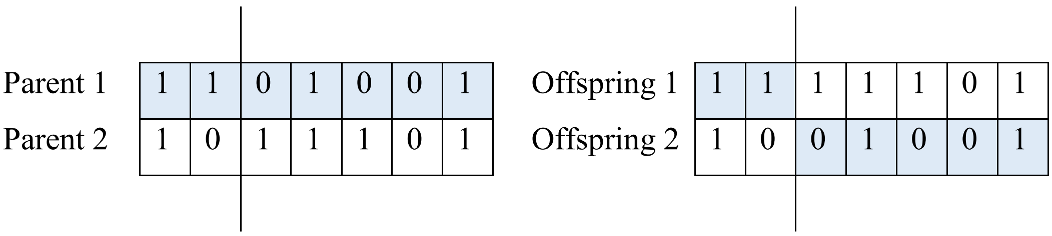


Figure 2.12 The example of one point crossover

b) Two-Point Crossover

Two-Point crossover randomly selects two crossover points within a chromosome, then interchanges two parent chromosomes between these points to create two new offspring shown as :

Parent 1	1	1	0	1	0	0	1	Offspring 1	1	1	1	1	0	0	1
Parent 2	1	0	1	1	1	0	1	Offspring 2	1	0	0	1	1	0	1

Figure 2.13 The example of two point crossover

c) Uniform Crossover

Uniform crossover decides (with some probability, known as mixing ratio) which parent will contribute how the gene values in the offspring chromosomes. The crossover allows parent chromosomes to be fixed at the gene level rather than the segment level (as with one and two point crossover). If the mixing ratio is 0.5 approximately, then half of the genes in the offspring consist of parent 1 gene and other half consist of parent 2. A set of offspring after uniform crossover would be

Parent 1	1	1	0	1	0	0	1	Offspring 1	1	1	0	1	1	0	1
Parent 2	1	0	1	1	1	0	1	Offspring 2	1	0	1	1	0	0	1

Figure 2.14 The example of uniform crossover

d) Arithmetic

Arithmetic crossover combines two parent chromosome vector to create two new offsprings based on this equation :

$$Offspring1 = a * Parent1 + (1-a) * Parent2 \quad (2.1)$$

$$Offspring2 = (1-a) * Parent1 + a * Parent2 \quad (2.2)$$

where a is a random weighting factor chosen before each crossover operation. Consider two parents (each of 4 float genes) selected for crossover. By applying two equations (2.1-2.2) and assuming the weighting factor a = 0.7, we obtain two resulting offspring. Thus, a set of offspring after arithmetic crossover would be :

Parent 1	0.3	1.4	0.2	7.4	Offspring 1	0.36	2.33	0.17	6.87
Parent 2	0.5	4.5	0.1	5.6	Offspring 2	0.402	2.981	0.149	5.842

Figure 2.15 The example of arithmetic crossover

e) Heuristic

Heuristic uses fitness value of two parent chromosomes to determine the direction of the search. Offsprings are produced based on this equations :

$$\text{Offspring1} = \text{BestParent} + r * (\text{BestParent} - \text{WorstParent}) \tag{2.3}$$

$$\text{Offspring2} = \text{BestParent} \tag{2.4}$$

where r is a random number between 0 and 1. It is possible that offspring1 will not feasible because it will happen if r is chosen such that one or more of its genes fall outside of the allowable upper or lower bounds. For this reason, heuristic crossover has an user defined parameter n for the number of trial times and find an r that results in a feasible chromosome. If a feasible chromosome is not produced after n trials, the worst parent is returned as offspring1.

- **Mutation**

Next variation operator is mutation. For each offspring, select some genes and change its value. Mutation varies based on the chromosome representation but it is up to you to decide how to apply mutation. If the encoding is binary (i.e. the value space of each gene have just two values 0 and 1), then flip the bit value of one or more genes. But if the gene value comes from a space of more than two values such as 1, 2, 3, 4, and 5, then the binary mutation will not be applicable and we should find another way. One way is by selecting a random value from such set of values as in the next diagram. Note that without mutation the offspring will have all of its properties from its parents. To add new features to such offspring, mutation took place. But because mutation occurs randomly, it is not recommended to increase the number of genes to be applied to mutation.

a) Bit Flip

The mutation operator simply inverts the value of the chosen gene. 0 goes to 1 and 1 goes to 0. This mutation operator can only be used for binary encoded.

0	0	1	1	0	1	0	⇨	0	0	1	0	0	1	0

Figure 2.16 The example of bit flip mutation

b) Inversion

In inversion mutation, we select a subset of genes like in scramble mutation, but instead of shuffling the subset, we merely invert the entire string in the subset.

0	1	2	3	4	5	6	⇨	0	1	4	3	2	5	6

Figure 2.17 The example of inversion mutation

c) Scramble

Scramble mutation is also popular with permutation representations. In this, from the entire chromosome, a subset of genes is chosen and their values are scrambled or shuffled randomly.

0	1	2	3	4	5	6	⇨	0	1	4	2	3	5	6

Figure 2.18 The example of scramble mutation

d) Order Changing or Swap

In order changing also called as swap mutation, the randomly selected bits values in a chromosome are exchanged. One example of order changing mutation is shown in Figure 2.19.

0	1	2	3	4	5	6	⇨	0	1	4	3	2	5	6

Figure 2.19 The example of order changing or swap mutation

e) Boundary

The mutation operator replaces the value of the chosen with either the upper or lower bound for that gene (chosen randomly). This mutation operator can only be used for integer and float genes.

f) Non-Uniform

The mutation operator increases the probability such that the amount of the mutation will be close to 0 as the generation number increases. This mutation operator prevents the population from stagnating in the early stages of the evaluation then allows the genetic algorithm to fine tune the solution in the later stages of evolution. This mutation operator can only be used for integer and float genes.

g) Uniform

The mutation operator replaces the value of the chosen gene with an uniform random value selected between the user-specified upper and lower bounds for that gene, This mutation operator can only be used for integer and float genes.

h) Gaussian

The mutation operator adds an unit Gaussian distributed random value to the chosen gene. The new gene value is clipped if it falls outside of the user-specified lower or upper bounds for that gene. This mutation operator can only be used for integer and float genes.

4. Termination Criterion

Termination is used to determine when the iterative should be stop. There are three kinds of termination conditions in the GA application, including :

a) Improvement of the fitness value

In this case, the algorithm terminates if the best value at *i*-th iteration is obtained and there is no longer better improvement after *i*-th iteration.

b) Time interval

In this case, the algorithm terminates if the current time of the algorithm exceeds a certain solving time upper bound.

c) Number of generations

In this case, the algorithm terminates if the number of generations exceeds a certain number.

d) The desired value is achieved

In this case, the algorithm terminates if we get the desired value after *i*-th iteration.

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CHAPTER 3
ADOPTED ALGORITHM

3.1 Taguchi's Method

Taguchi's method is an iterative optimization procedure based on orthogonal array (OA) which can be used to find near-optimal settings. OA is an important parameter in Taguchi's method which provides a systematic way to determine the control parameters of the experimental run. Taguchi's method was developed and widely used for the optimization in manufacturing processes [12]. Taguchi's method is then adopted to other engineering fields, such as electromagnetic and microwave circuits, power electronics and wireless communications [13]. Taguchi's method implementations are illustrated in Fig. 3.1

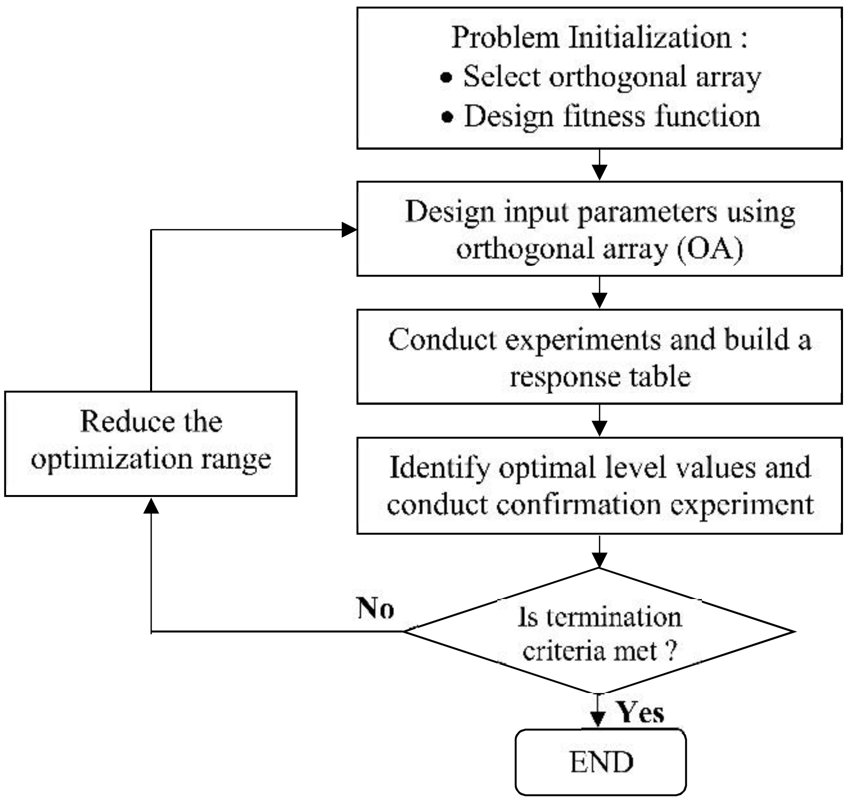

Figure 3.1 Flowchart of Taguchi's method

The first step is determine the orthogonal array (OA). Design of OA construction OA(N, k, s, t) is based on optimization parameters. Where N, k, s, and t

denote the number of experiments need to be carried out per design iteration, the number of parameters that need to be optimized, corresponding values for the levels depend on the parameters an vary in different applications and strength, respectively. Refer to [9], levels is set to be three (s = 3) to characterize nonlinear effect and sufficient for each input with a strength of 2 (t = 2) is efficient for most problems because rows can be resulted in a small number. Due to the purpose of my research is to optimize LTE-A network throughput with consideration on coexistence both of Wi-Fi and IoTD under LAA framework, I determine 4 parameters (k = 4) to be optimized, which are number of IoTD, bandwidth (number of Physical Resource Block/PRB), resource scheduling and Channel occupancy Time (COT). After the values of k, n, t have determined, the number of experiments N can be calculated by

$$N = s^p \tag{3.1}$$

where p is a positive integer number starting with 2, namely, p = 2, 3, …. . Thus, the OA construction of $OA(9,4,3,2)$ has selected. The detail OA construction of Taguchi's method can be explained in Table 3.1 and 3.2,

Tabel 3.1 Array Table for Optimization Parameters

Experiment	**Number of IoTD**	**Bandwidth**	**Scheduler**	**COT**
1	1	1	1	1
2	1	2	2	3
3	1	3	3	2
4	2	1	2	2
5	2	2	3	1
6	2	3	1	3
7	3	1	3	3
8	3	2	1	2
9	3	3	2	1

The second step is design fitness function. It chosen based on optimization goal. In this case, I determine theoretical system throughput as fitness function, which can be expressed as [14]

$$TP_{1s} = N_{RB} \,.\, N_{REpRB} \,.\, modBits \,.\, CR \,.\, TS_{1s} \tag{3.2}$$

where N_{RB} is the total number of resource blocks per time slot (0.5 ms), for a 10 MHz

Tabel 3.2 Variation Levels of Optimization Parameters

Levels / Parameters	1	2	3
Number of IoTD	20	50	100
Bandwidth	5	10	20
Scheduler	RR	BET	PF
COT	5 ms	7 ms	10 ms

Tabel 3.3 4-bit CQI Table for LTE [15]

CQI Index	Modulation	Code Rate x 1024	Efficiency
0	out of range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.377
4	QPSK	308	0.6016
5	QPSK	449	0.877
6	QPSK	602	1.1758
7	16 QAM	378	1.4766
8	16 QAM	490	1.9141
9	16 QAM	616	2.4063
10	64 QAM	466	2.7305
11	64 QAM	567	3.3223
12	64 QAM	666	3.9023
13	64 QAM	772	4.5234
14	64 QAM	873	5.1152
15	64 QAM	948	5.5547

Tabel 3.4 Channel Bandwidth and Physical Resource Block (PRB) Specifications [16]

Bandwidth (MHz)	1.4	3	5	10	15	20
Number of PRBs	6	15	25	50	75	100
Number of occupied subcarriers	72	180	300	600	900	1200

channel the total number of resource blocks per time slot is 50. N_{REpRB} is the number of Resource Elements (RE) per RB. For normal cyclic prefix, one RB contains 12 sub-carriers and 7 OFDM symbols, thus there are 84 resource elements in one RB. The *modBits* variable represents the number of bits carried by one symbol in a given modulation (i.e. for 64 QAM, *modBits* is equal to 6). And the last, *CR* is the code rate of error correction coding and *TS*1s is a constant transforming the throughput from 0.5 ms scale to 1 s scale. All these values are taken from Table 3.3 and 3.4.

3.2 Genetic Algorithm (GA)

Genetic algorithm is a heuristic search algorithm inspired by Darwin's theory of natural selection. The algorithm goes through iterative way such as reproduction, crossover and mutation. Begin with randomly generated composed of a group of solutions is represented by the number of chromosomes also called as

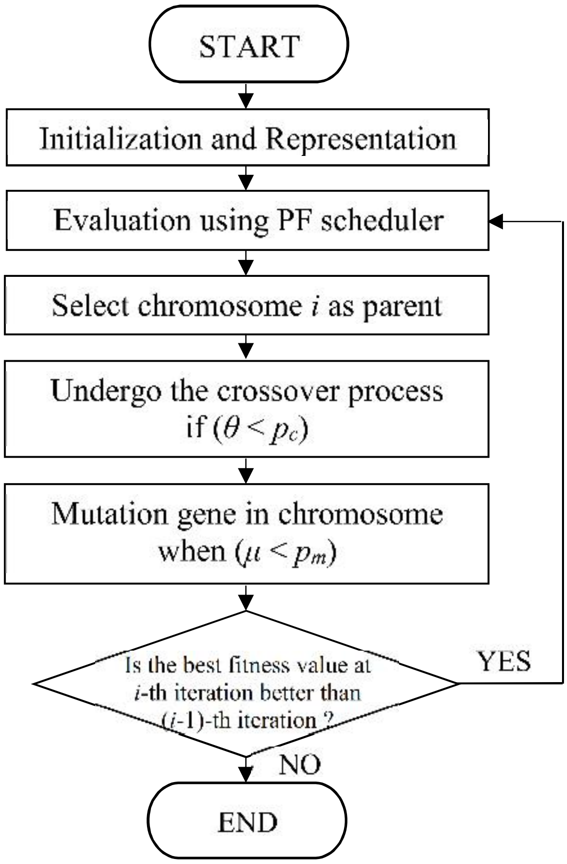

Figure 3.2 Genetic Algorithm (GA) flowchart

one population. Each chromosome composes a number of genes, and a value of each gene can be either binary, integer, character, or real number depends on the problem to be solved. Then, select chromosome as parent using fitness proportionate selection method, such as roulette wheel, tournament, and ranking based on fitness value of every chromosome. The higher fitness value, the higher probability of its chromosome to be chosen. Combine genes from the existing chromosomes to produce new ones as called as off-springs. And the final step of GA is mutation. By through some iterations, a set of optimal solutions is obtained and iteration will be stopped when condition is met. Figure 3.2 and Table 3.5 show GA flowchart and simulation parameters.

Tabel 3.5 GA Simulation Parameters

Parameters	Characterization/Values
Population size	200
Number of genes	50
Crossover method	One-point crossover
Crossover rate, p_c	0.9
Selection method	Roulette-Wheel
Mutation method	Order changing mutation
Crossover rate, p_c	0.001
Termination criterion	Improvement of fitness value

3.2.1 Initialization and Representation

The first step in GA is population initialization and chromosome coding representation. In LTE-A downlink approach, we have *N* users with $N \in [1, 50]$ and *K* allocated Physical Resource Blocks (PRBs) with *K* is randomly generated number of [1,50]. We set a value of 200 for population size as the number of chromosomes in one population. In GA, population is a set of solutions of the problem. Each chromosome composed of *m* genes as the number of users. And each gene indicates

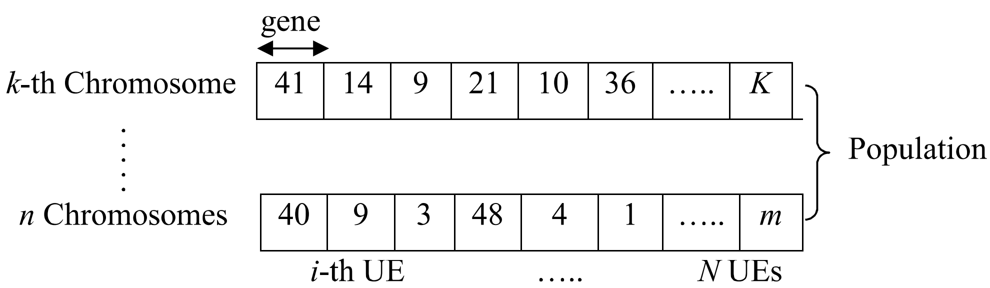

Figure 3.3 GA chromosome coding

how many PRBs have been assigned to a distinctive user or how many times a particular user has been scheduled randomly. From Figure 3.3, it can be described that User Equipment (UE) 1 has been scheduled for 41 times, and UE 2 has been assigned as many as 14 PRBs, and so on.

3.2.2 Evaluation

Each chromosome is known as a solution and each solution should be tested to measure how optimum the solution is. In the evaluation phase, we determine Proportional Fair (PF) scheduler as a fitness function to examine the fitness on our desired result. In this stage of GA, each chromosome is evaluated according to a fitness function by using this following equation :

$$f_k(t) = \sum_{i=0}^{K} \frac{r_{(u,i)}}{\overline{R_\iota(t)}} \qquad , \overline{R_\iota(t+1)} = \left(1 - \frac{1}{t_c}\right) *, \overline{R_\iota(t)} + \frac{1}{t_c} * r_{(u,i)} \quad (3.3)$$

where $f_k(t)$ is fitness function of chromosome k at TTI t, $r_{(u,i)}$ is instantaneous transmission rate for user i on resource block u is calculated based on quality of channel, $\overline{R_\iota(t)}$ is past average throughput of user i at TTI t, t_c is time slot. In this case, we determine time slot as weighted factor as moving average when Round Robin (RR) scheduler is used to allocate user.

3.2.3 Roulette-Wheel Selection Method

Many selection techniques can be employed as reproduction in GA, such as tournament, ranking and roulette-wheel. Roulette-Wheel also called stochastic sampling with replacement is the simplest and useful method for recombination. This method will pick the chromosome/individual with high probability, which proportionate to its fitness. Some stages are involved in Roulette-Wheel selection as shown in Figure 3.4.

From previous stage of GA, we got a set of fitness value from all chromosomes. After that, we count its expected selection probability corresponds to its fitness value by dividing the probability of each chromosome to the sum of chromosome probability by using this equation

$$p_k = \frac{f_k}{\sum_{j=1}^{n} f_j} \quad (3.4)$$

where f_k is fitness of i-*th* chromosome, and $\sum_{j=1}^{n} f_j$ is fitness total of all chromosomes.

To select chromosome as parent, generate a random number in the range of [0,1]. Individual whose has expected selection probability in the segment spans of the random number to be chosen. The step is repeated until desired individual number is obtained. This process also known as mating population. To gain the understanding about individual selection, we give an instance as shown in Table 3.6, there are a number of generated random R_i and expected selection probability of each individual p_i. Based on the case given in Table 3.6, chromosome 3 and 1 are chosen as parent. Therefore, individual whose has greater probability also has greater chance to be chosen. In this case, we generate two random numbers for each iteration due to we want get two individual parents.

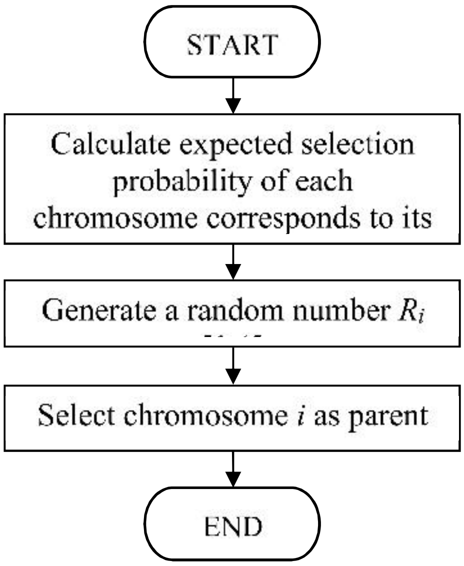

Figure 3.4 Roulette-Wheel selection method

Tabel 3.6 GA Simulation Parameters

Chromosome index, i	Expected selection probability, p_i	Random number generation, R_i
1	0.00176	$R_1 = 0.27683$ $R_2 = 0.00152$
2	0.01478	
3	0.27683	
⋮	⋮	
n	0.38921	

3.2.4 One-Point Crossover

Crossover is a combination (mating) process between two parents to create new chromosome/individual as called as off-spring. The behind idea of this

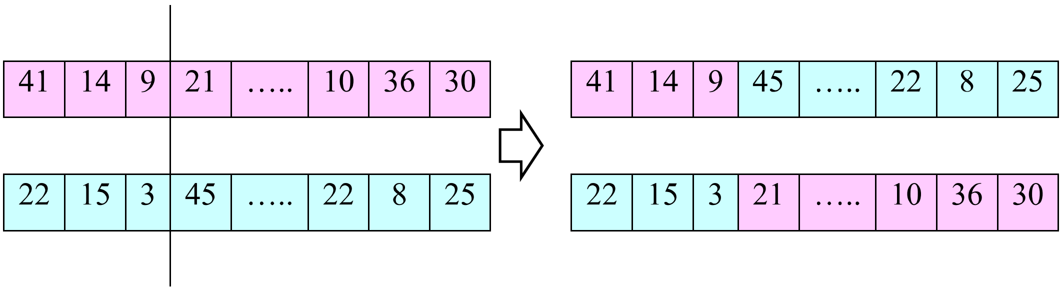

Figure 3.5 Illustration of one-point crossover

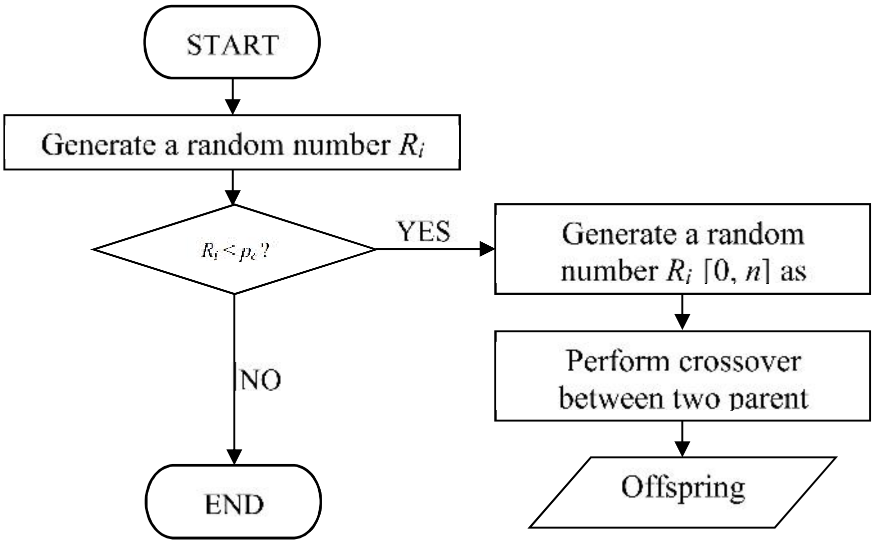

Figure 3.6 One-point crossover flowchart

process is creates a better individual when two goodness of parents are combined. Before performing crossover, we should understand when the chromosome need to do crossover process. If generated random number is smaller than crossover probability, the chromosome should be perform crossover process. Crossover probability indicates a ratio of how many couples/parents will be picked for mating. The purpose of this stage is as a convergence operator which is intended to pull the population towards a local minimum/maximum. Since the end goal is to bring the population to convergence, selection/crossover happen more frequently (typically every generation).

In this case, we determine crossover probability is 0.9. It means that it will perform whatever crossover operator we have chosen 0.9 or equal to 90% of the time and the remaining 0.1 or equal to 10% of the time, it will pass the parents unmodified into the offspring pool. The illustration and flowchart of one-point crossover are shown in Figure 3.5 and 3.6. For instance, random number R_i of 3 is selected as crossover point. Therefore, crossover can be done by splitting both parental genes from $R_i + 1$ until m as represented in Figure 3.5.

3.2.5 Order Changing Mutation

Mutation is the last stage in Genetic Algorithm. Different from crossover's role as convergence operation, mutation is used for divergence operation which is intended to occasionally break one or more members of a population out of a local minimum/maximum space and potentially discover a better minimum/maximum space. Thus, this should happen less frequently, and typically only effects a few members of a population (if any) in any given generation. Same as crossover process, before performing mutation process, we should check a condition. When generated random number is smaller than mutation probability, mutation should be performed.

In this case, we determine mutation probability of 0.001. It means that mutation could be happen only on one gene out of chromosome length. The determination of mutation probability should be much smaller than crossover probability to avoid premature convergence on a local maximum or minimum. Too high a mutation probability means that convergence is slow or it does not occur. This following figure 3.7 and 3.8 show the illustration and flowchart of order changing mutation. From Figure 3.7, we can see two genes of individual are selected and exchanged.

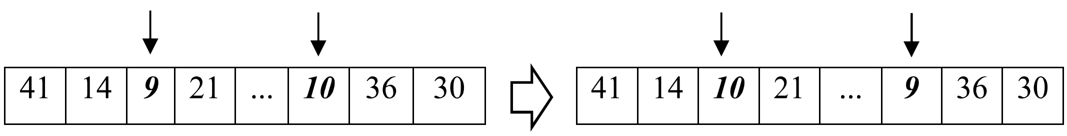

Figure 3.7 Illustration of order changing mutation

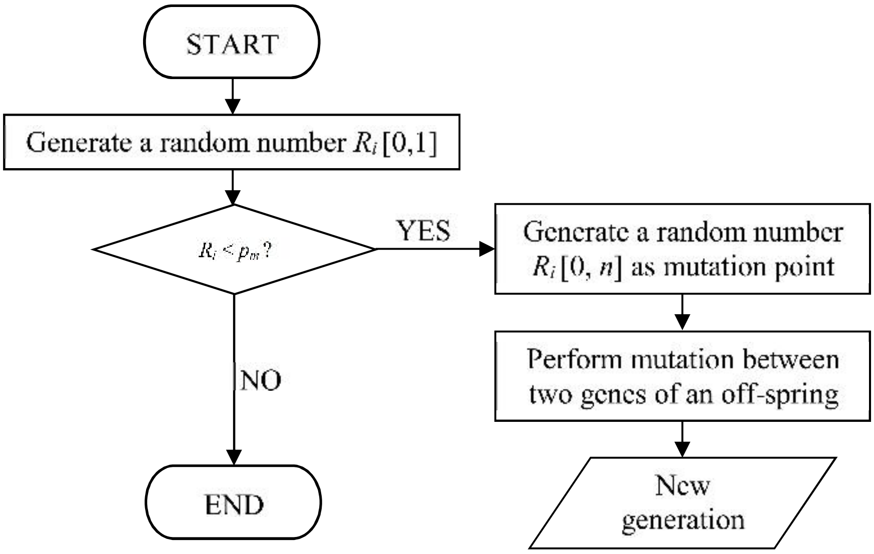

Figure 3.8 Order changing mutation flowchart

3.2.6 Termination Criterion

We consider to stop the algorithm when there is no longer produces better improvement in the fitness of the best individual for successive iterations.

CHAPTER 4
SIMULATION SETUP, RESULTS AND DISCUSSIONS

In LTE-A system, we use CA to combine different carriers and expand bandwidth. To ensure the cell edge user to get a good throughput, we utilize some scheduler and the best one will be chosen, then. Also, consider about IoTD in LAA deployment scenario to analyze resource allocation algorithms for industry 4.0 application.

4.1 Popagation and Channel Models

Pathloss model is used for describing signal attenuation between transmitter and receiver antenna as a function of the propagation distance. In coexistence of two component carrier both of licensed and unlicensed, we consider four types of channel model based on different coverage and antenna height. For licensed spectrum in urban environment, we use ITU UMa [17] for macro cell users to macro cell Base Station (BS) scenario and Winner II-C2 [18] for macro cell users to small cell Base Station (BS) scenario. Then, for licensed spectrum in suburban environment, we consider Cost-231 Hata model [19] for macro cell users to macro cell Base Station (BS) scenario and Winner II-C2 for macro cell users to small cell Base Station (BS) scenario and Industrial Indoor Channel [20] is used for unlicensed spectrum in LAA-LTE network.

4.1.1 ITU UMa

For macro cell in urban environment, we adopt ITU UMa of channel model. It has different equation based on LOS and NLOS propagation as seen in Table 4.1. d'_{BP} denotes break point distance = 4 $h'_{BS} h'_{MS} f_c/c$, where f_c is the centre frequency in Hz, $c = 3.0\times10^8$ m/s is the propagation velocity in free space, and h'_{BS} and h'_{MS} are the effective antenna heights at the Base Station and the Mobile Station, respectively. The effective antenna heights h'_{BS} and h'_{MS} are computed as follows: $h'_{BS} = h_{BS} - 1.0$ m, $h'_{MS} = h_{MS} - 1.0$ m, where h_{BS} and h_{MS} are the actual antenna heights, and the effective environment height in urban environments is assumed to be equal to 1.0 m.

Tabel 4.1 ITU UMa Path loss [17]

Link	Path loss (dB)	Shadow fading std (dB)	Applicability range, antenna height default values
LOS	$PL = 22.0\log_{10}(d) + 28.0 + 20\log_{10}(f_c)$ $PL = 40.0\log_{10}(d_1) + 7.8 - 18.0\log_{10}(h'_{BS}) - 18.0\log_{10}(h'_{MS}) + 2.0\log_{10}(f_c)$	$\sigma = 4$ $\sigma = 4$	10 m < d < d'_{BP} $d'_{BP} < d_1$ < 5 000 m h_{BS} = 25 m, h_{MS} = 1.5 m
NLOS	$PL = 161.04 - 7.1\log_{10}(W) + 7.5\log_{10}(h) - (24.37 - 3.7(h/h_{BS})^2)\log_{10}(h_{BS}) + (43.42 - 3.1\log_{10}(h_{BS}))(\log_{10}(d)\text{-}3) + 20\log_{10}(f_c) - (3.2(\log_{10}(11.75\, h_{MS}))^2 - 4.97)$	$\sigma = 6$	10 m < d < 5 000 m h = avg. building height W = street width h_{BS} = 25 m, h_{MS} = 1.5 m, W = 20 m, h = 20 m The applicability ranges: 5 m < h < 50 m 5 m < W < 50 m 10 m < h_{BS} < 150 m 1 m < h_{MS} < 10 m

4.1.2 WINNER II

WINNER II pathloss model is a continuity of the channel modelling work of WINNER I and extended the model features, frequency range and the number of scenarios. It designs for many kind of scenarios indexed by A1 up to D2a, and suitable for indoor office, large indoor hall, indoor-to-indoor hall, indoor-to-outdoor, urban micro cell, bad urban micro cell, outdoor-to-indoor, stationary feeder, suburban macro cell, urban macro cell, rural macro cell, and rural moving networks can be applied to wireless communication operating at frequency range of 2 – 6 GHz with up to 100 MHz RF bandwidth and supports multi-antenna technologies, polarization, multi-user, multi-cell and multi-hop networks. We consider this pathloss model with scenario C1 and C2 for macrocell users to small cell BS in suburban and urban macro cell environment, respectively. The pathloss equations are listed in Table 4.2 based on LOS and NLOS propagation. A, B and C are pathloss exponent, intercept and pathloss frequency dependence, respectively. d_{BP} is computed as follows: $d_{BP} = 4\ h_{BS}\ h_{MS}\ f_c/c$, where h_{BS}, h_{MS}, f_c, and c have the same definition as explanation before.

Tabel 4.2 WINNER II Path loss [18]

Scenario	**Link**	**Path loss (dB)**	**Shadow fading std (dB)**	**Applicability range, antenna height default values**
C1 Suburban	LOS	A = 23.8, B = 41, C = 20 $PL = 40.0\log_{10}(d) + 11.65 - 16.2\log_{10}(h_{BS}) - 16.2\log_{10}(h_{MS}) + 3.8\log_{10}(f_c/5)$	$\sigma = 4$ $\sigma = 6$	$30\text{ m} < d < d_{BP}$. $d_{BP} < d < 5\text{ km}$, $h_{BS} = 25\text{ m}$, $h_{MS} = 1.5\text{ m}$
	NLOS	$PL = (44.9 - 6.55\log_{10}(h_{BS}))\log_{10}(d) + 31.46 + 5.83\log_{10}(h_{BS}) + 23\log_{10}(f_c/5)$	$\sigma = 8$	$50\text{ m} < d < 5\text{ km}$. $h_{BS} = 25\text{ m}$, $h_{MS} = 1.5\text{ m}$
C2 Typical Urban Macro cell	LOS	A = 26, B = 39, C = 20 $PL = 40.0\log_{10}(d) + 13.47 - 14\log_{10}(h'_{MS}) + 6\log_{10}(f_c/5)$	$\sigma = 4$ $\sigma = 6$	$10\text{ m} < d < d'_{BP}$. $d'_{BP} < d < 5\text{ km}$, $h_{BS} = 25\text{ m}$, $h_{MS} = 1.5\text{ m}$
	NLOS	$PL = (44.9 - 6.55\log_{10}(h_{BS}))\log_{10}(d) + 34.46 + 5.83\log_{10}(h_{BS}) + 23\log_{10}(f_c/5)$	$\sigma = 8$	$50\text{ m} < d < 5\text{ km}$. $h_{BS} = 25\text{ m}$, $h_{MS} = 1.5\text{ m}$

4.1.3 Cost-231 Hata

For macro cell, we adopt Cost-231 Hata of channel model as seen in Table 4.3. f is the frequency (MHz), H_b is the base station antenna height (m), H_m is mobile antenna (meters), d is the distance between the BTS and MS (kilometers), C is a constant factor (C = 0 dB for medium and suburban macro) and $a(H_m)$ is mobile antenna correction factor for suburban or rural (flat) environment :

$$a(H_m) = (1.1 \log_{10} f - 0.7)\, H_m - [1.56 \log_{10} (f) - 0.8] \tag{4.1}$$

Tabel 4.3 Cost-231 Hata [19]

Scenario	Path loss (dB)	Applicability range, antenna height default values
Suburban Macro	$PL = 46.3 + 33.9 \log_{10} (f) - 13.82 \log_{10} (H_b) - a(H_m) + [44.9 - 6.55 \log_{10} (H_b)] \log_{10} (d) + C$	$1500 \text{ MHz} \le f \le 2000 \text{ MHz}$ $1 \text{ km} < d < 20 \text{ km}$ $30 \text{ m} \le H_b \le 200 \text{ m}$ $1 \text{ m} \le H_m \le 10 \text{ m}$

4.1.4 Industrial Indoor Channel

This channel model is suggested by [20] and designed for industrial environment in the same factory floor which operates at frequency band of 900 MHz, 2.4 GHz and 5.2 GHz to describe both large-scale and temporal fading with transceiver antenna is installed at 2 m above ground level. Assume free-space propagation of device-to-BS distance is 15 m, then path loss in decibel L_{dB} can be calculated as equation in Table 4.4,

Tabel 4.4 Industrial Indoor Channel [20]

Scenario	Path loss (dB)	Applicability range
Free-space	$L_{dB} = 70.28 + 10 \times 2.59 \times \log_{10}(d/15)$ $L_{dB} = 20 \times \log_{10} (4\pi \times d \times f/c)$	$15 \text{ m} < d$ $d < 15 \text{ m}$

where d as link distance in meters, f and c denote the carrier frequency and the light speed respectively.

4.2 Resource Scheduling

Resource scheduling is an user allocation technique to provide a service based on demand. According to the OA construction selection in the previous chapter, we determine three levels of scheduler parameter in LTE network, in term of throughput is poor. Based on the previous research [21], there are many kinds of LTE downlink scheduler, such as Best CQI (BCQI), Proportional Fair (PF), Kwan Maximum Throughput (KMT), Blind Equal Throughput (BET) and Round Robin (RR). Due to of the optimization goal, we only focus on the throughput index. In this case, we utilize 3 lower schedulers rank for downlink communication to be observed in order to achieve better system throughput. The three lowest throughput are RR, BET and PF. But, PF is the most common used scheduler in cellular network due to its trade-off between fairness and throughput index. The performance comparison among five scheduler based on throughput index is listed in Table 4.5,

Tabel 4.5 Different Downlink Scheduling Schemes Performance in LTE Network [21]

Performance Index	Scheduler				
	RR	**BCQI**	**KMT**	**PF**	**BET**
Throughput	Poor	Good	Good	Medium	Poor

In [22] evaluated that throughput for BCQI, KMT and PF are increased as the increasing number of UEs in the same cell, while the remaining are decreased. It caused by multiuser diversity. Three kinds of adopted scheduler are explained as follows :

4.2.1 Round Robin (RR)

Round Robin is the simplest way and fairest algorithm of resource allocation since user will be scheduled in equally amount without any priority and does not consider about CQI. The Modulation Coding Scheme (MCS) will be given to every user based on wideband CQI. Hence, user is not required to send a feedback to eNodeB. The mechanism of RR can be seen in Figure 4.1.

First, RR generates a list of active users based on first come first serve basis. Then, available resource blocks (RBs) are divided into several RBs and allocated to users in the list. In this case, we assume that one Scheduling Block (SB) is composed of two adjacent PRBs with 180 kHz of frequency bandwidth which has two time slots that can be called as one TTI as explained in Figure 4.2. If the number of users is greater than the number of PRBs, the remaining user who has not scheduled will be scheduled in the next TTI. Otherwise, if the number of users is smaller than the PRB availability, all users can be scheduled in the same TTI. When all users have scheduled in the current TTI, but there are a remaining number of PRB, users will be cyclically scheduled based on their ordering number.

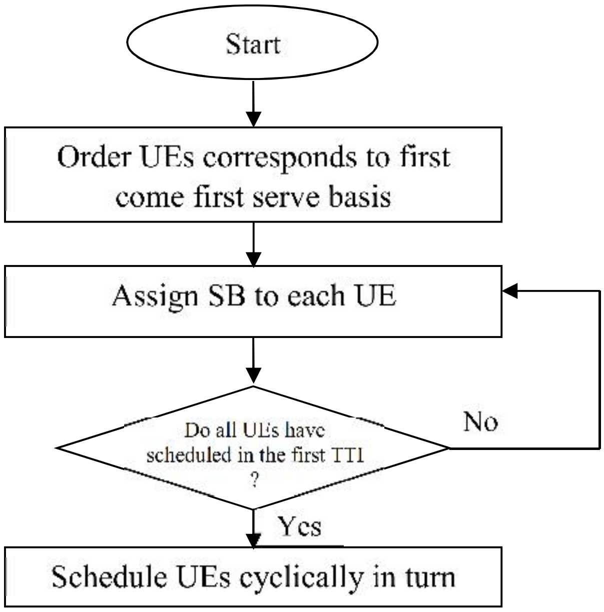

Figure 4.1 Flowchart of Round Robin (RR) scheduler mechanism

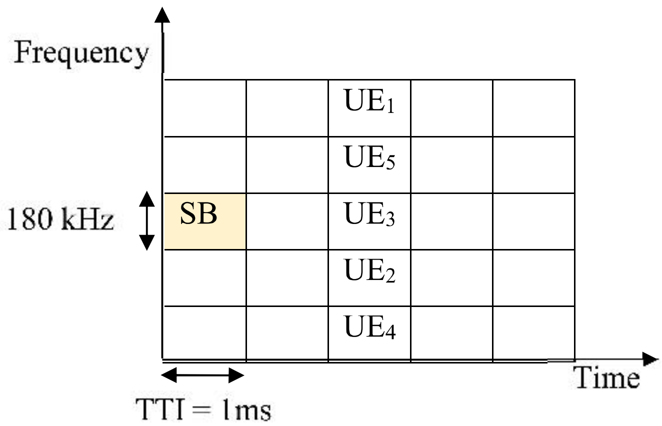

Figure 4.2 Scheduling Block (SB) of radio communication

4.2.2 Blind Equal Throughput (BET)

Blind Equal Throughput is included as channel-unaware aims to provide an equal throughput among all UEs without taking CQI into account. In this scheduler also does not require feedback from UE, and MCS will be given to user according to wideband CQI. BET utilize past average throughput of user to schedule user. The assumption about SB is same as in RR scheduler and can be shown in Figure 4.2. BET mechanism can be seen in Figure 4.3. Unlike Round Robin, this scheduler has a priority metric in assigning user to PRB. Priority metric for BET is given by:

$$m_{i,k}^{BET} = \arg max_{(i)} \frac{1}{\overline{R^{i}}(t-1)} \quad (4.2)$$

with

$$\overline{R^{i}}(t) = \beta\overline{R^{i}}(t-1) + (1-\beta)r^{i}(t) \quad (4.3)$$

where $\overline{R^{i}}(t)$ is past average throughput of user i at time t, β is exponential moving average with ($0 \leq \beta \leq 1$), $r^{i}(t)$ is achievable rate of user i at time t with MCS given

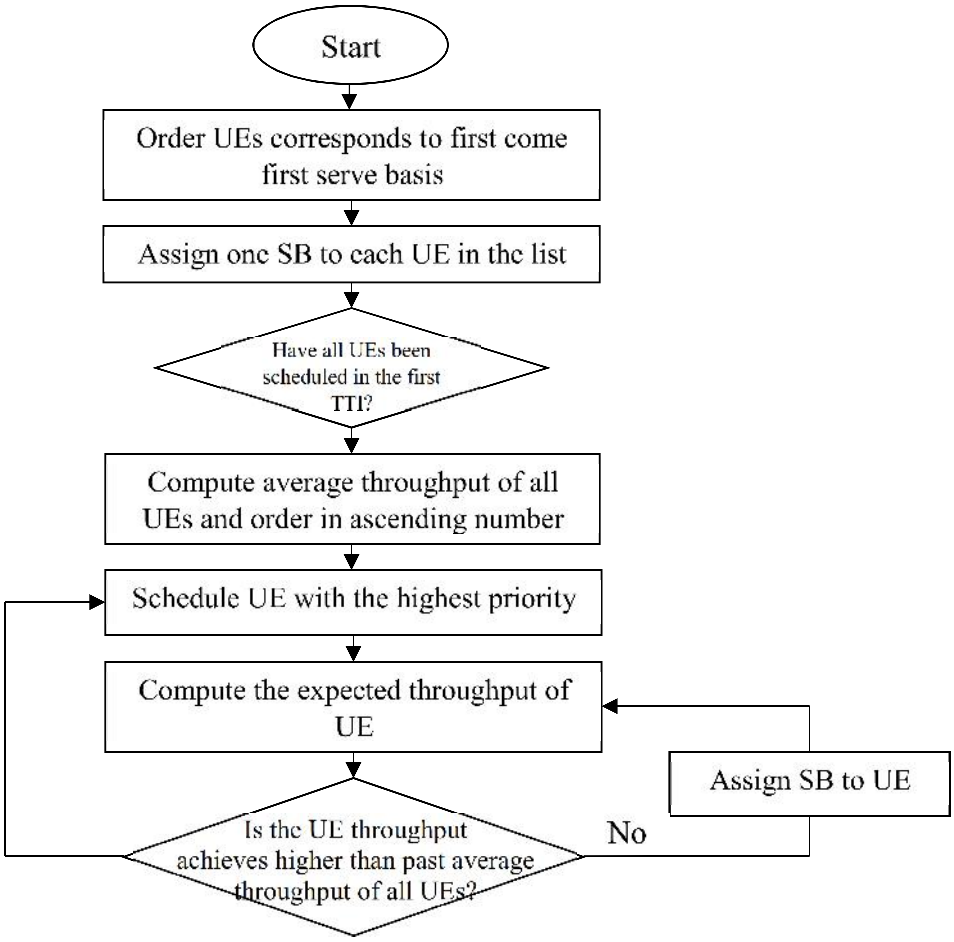

Figure 4.3 Flowchart of Blind Equal Throughput (BET) scheduler mechanism

to user *i* from wideband CQI. We compute past average throughput by averaging the system throughput when RR scheduler is used for 20 TTIs. Scheduler recalculates and updates the expected average throughput of UE at every TTI and uses this to compares with past average throughput of other UEs. If a user is no longer to be the lowest, SB will be assigned to other user who has the highest priority until better average throughput is achieved. Based on priority metric, scheduler will assign one SB to UE with the lowest average throughput.

4.2.3 Proportional Fair (PF)

The last adopted resource algorithm is Proportional Fair as known as channel-aware scheduler. Unlike RR and BET scheduler, this algorithm consider about channel condition. This scheduling is the most common used in cellular network due to the trade-off between throughput and fairness. MCS is given to users based on their UE feedback to eNodeB with 4-bit CQI as listed in Table 3.3. The procedure of PF scheduler is shown in Figure 4.4. Same with BET scheduler, PF also utilize past average throughput of user and has a priority metric in assigning user to PRB as follows :

$$m_{i,k}^{PF} = \arg max_{(i)} \frac{d_k^i(t)}{\overline{R^i}(t-1)} \tag{4.4}$$

with

$$\overline{R^i}(t) = \begin{cases} \beta\overline{R^i}(t-1) + (1-\beta)d_k^i(t) & , if\ user\ i\ is\ selected \\ \beta\overline{R^i}(t-1) & , if\ user\ i\ is\ not\ selected \end{cases} \tag{4.5}$$

$$d_k^i(t) = \log(1 + SINR_k^i(t)) \tag{4.6}$$

$$SINR_k^i(t) = \frac{P_{r,i}}{I_f + N_o} \tag{4.7}$$

$$P_{r,i} = P_{t,s} h_{i,k} G_s PL_{i,s} \tag{4.8}$$

$$I_f = P_{t,f} h_{i,k} G_f PL_{i,f} \tag{4.9}$$

where d_k^i is achievable data rate of user *i* on the *k*-th PRB, $P_{r,i}$ is received power of user *i,* $P_{t,s}$ is transmit power of serving eNodeB, $h_{i,k}$ is fading channel gain of user *i* on the k-th PRB, G_s is antenna gain of serving eNodeB, $PL_{i,s}$ is pathloss of user i to serving eNodeB, I_f is interference power, $P_{t,f}$ is transmit power of interference cell, G_f is antenna gain of interference cell, $PL_{i,f}$ is pathloss of user i to interference cell, N_o is thermal noise power. In this case, fading channel gain is modeled as zero mean circular symmetric complex Gaussian Random Variable (RV) with variance σ^2 can be denoted as $C\aleph(\mu,\sigma^2)$. Due to μ is equal to zero, so it becomes $C\aleph(0,\sigma^2)$, and variance depends on the distance of user i to Base Station. The distance of user i to Base Station can be calculated by

$$D_i^b = \sqrt{(x_i - x_b)^2 + (y_i - y_b)^2} \tag{4.10}$$

where x_i is x-point value of user i, x_b is x-point value of base station b, y_i is y-point value of user i, y_b is y-point value of base station b.

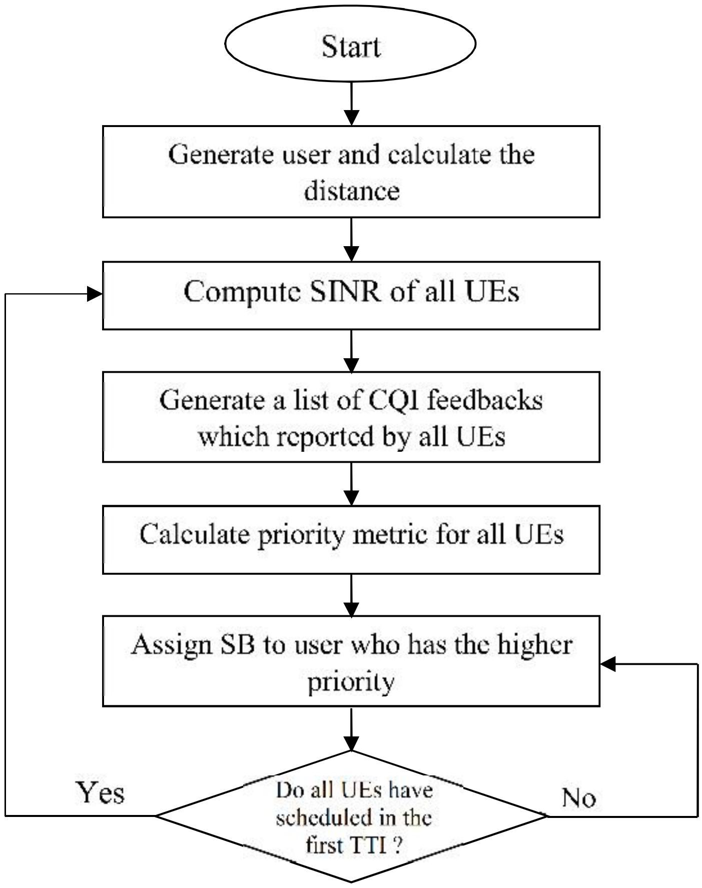

Figure 4.4 Flowchart of Proportional Fair (PF) scheduler mechanism

4.3 OFDMA System

OFDMA stands for Orthogonal Frequency Division Multiple Access as multi-user variant of OFDM technique. OFDMA system leads more efficient use of allocation because allocates a subset of sub-carriers to several users, meanwhile OFDM system allocates all subcarriers of OFDM symbol only to one user. OFDMA has some advantages, such as provides multi-user diversity because of OFDMA allows different users to transmit over different parts of the frequency spectrum known as traffic channel. Hence different users see different channel qualities. And another benefit is leads to be better BER performance because of fading environment. On the other side, OFDMA makes transmitter and receiver algorithm complex for data processing/extraction because of permutation and de-permutation rules of subcarriers for allocation and deallocation to subchannels.

4.3.1 LTE Downlink Frame Structure

In OFDMA, users are allocated a specific number of subcarriers for a predetermined amount of time uses time-frequency strategy of user scheduling. The smallest unit of allocating resource to user is Physical Resource Block (PRB). One radio frame of OFDMA system is divided into 10 subframes. Each subframe has 1 ms duration and consists of 2 time slots, each 0.5 ms as called as one Transmission

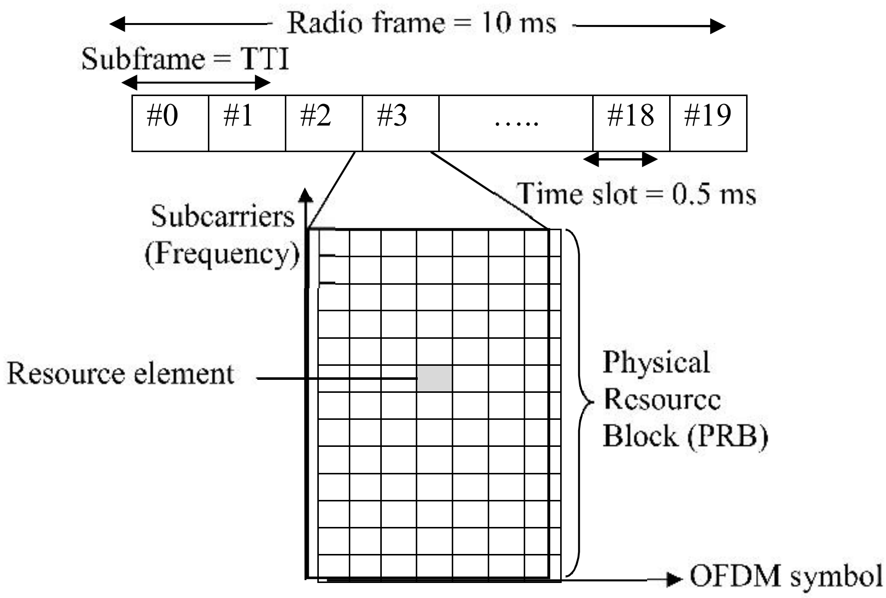

Figure 4.5 LTE-A downlink frame structure and resource grid

Time Interval (TTI). Each time slot consists of either 6 or 7 ODFM symbols (in time domain), depends on either normal or extended cyclic prefix is employed and 12 consecutive subcarriers (in frequency domain). And the total number of available subcarriers depends on the overall transmission system bandwidth. Each box within the grid represents a single subcarrier for one symbol period and referred as a resource element. LTE-A downlink frame structure and resource grid is represented in Figure 4.5.

4.4 Fair Coexistence in Unlicensed Band

To enhance a fair coexistence between LTE, Wi-Fi and IoT networks in LAA framework, we propose LAA (Licensed Assisted Access) based LBT (Listen Before Talk) as access scheme. In this case, we consider to adopt on category 2 for fair coexistence among three existing networks. To avoid data collision, we assume LTE-A data uses LBT-based protocol, otherwise, both Wi-Fi and IoT data will be conducted by CSMA/CA protocol. But, we would not explain the detail of CSMA/CA in our research. We only focus on LTE-A network. FBE-based LTE-LAA is briefly described in the following :

4.4.1 FBE-based LTE-LAA

In the unlicensed band, we can not adopt LTE-LAA based OFDMA frame structure because LTE-LAA is not the only one existing network. Both of Wi-Fi and IoT networks are also utilize unlicensed band to provide a service to their User Equipments (UEs). FBE based LBT is based on a fixed frame structure. Frame is divided into Channel Occupancy Time (COT) and idle period. LTE-LAA occupy the channel during COT and remain silent, while both Wi-Fi and IoT occupied during idle period. Before occupying the channel, all equipments shall perform CCA (Clear Channel Assessment) for channel observation time $\geq$ 20 μs using energy detection (ED) to check if the channel is free or occupied and CCA is performed once in each Fixed Frame Period (FFP). If the equipment finds the channel is clear, it may transmit immediately for a channel occupation time between [1 ms, 10 ms]. Otherwise, it shall transmit for the next FFP.

COT is designated for LTE data transmissions of up to 10 subframes, and should not exceeds 10 ms and the minimum Idle Period shall be at least 5% of the COT. In this research, the length of FFP and COT is assumed to be 20 ms and 5 ms respectively. Hence, the duration of idle period is 15 ms. And LAA bandwidth is fixed to be 20 MHz.

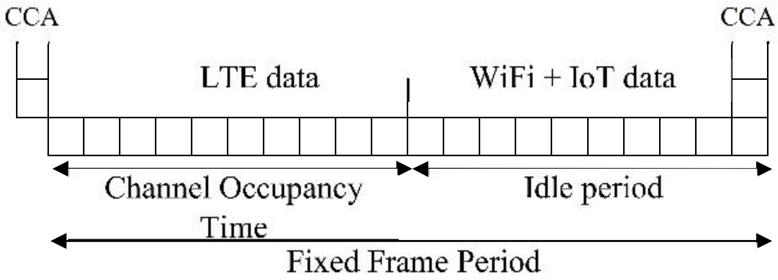

Figure 4.6 Adopted LTE-LAA frame structure and timing

4.5 Network Simulation and Parameters Settings

In the network simulation framework, we deploy 4 cells in a HetNet, which are a small cell Base Station (BS) and an eNodeB serve 1 cell and 3 cells, respectively. There is a small cell in a cluster of macro sector. We assume the LTE UEs are static. In a HetNet, covers both of LTE UEs and IoTD. In a small cell cluster, there is a Wi-Fi hotspot. Therefore, some sectors have the same eNodeB position due to sectorization. In the DL mode, several system bandwidths with several number of PRBs are considered. Moreover, several resource schedulers are assumed, where each UE is served by a single PRB. The whole of parameters used in this simulation is listed in Table 4.6

Tabel 4.6 Simulation Parameters

Parameters	Characterization/Values
Cellular layout	Hexagonal grid, 1 eNodeB, 3 sector antennas
Sector antenna pattern	3GPP antenna pattern for 120^{o} sector
CA configuration	2 GHz (PCC) 5.2 GHz (SCC)
System bandwidth	**PCC:** 20 MHz (~ 100 PRBs) **SCC:** 20 MHz (~ 100 PRBs)
Simulation length	**Licensed:** 50 TTIs **Unlicensed:** 10 FFPs
TTI	1 ms
COT	5 ms

Frequency re-use	1
Downlink scheduler	RR, BET, PF
Cell per cluster	2
Cluster per macro sector	1
Small cell radius	500 m
Macro cell radius	1 km
Cell selection criteria	**LAA UEs:** RSS threshold is -72 dBm **Wi-Fi STAs:** RSS threshold is -82 dBm
User arrival distribution	Random and Uniform distribution
Antenna height	25 m
Thermal noise density	-174 dBm/Hz
Antenna gain	**Macro cell:** 18 dB **Small cell:** 2 dB
Cable loss (Tx)	2 dB
TX power	**PSC:** 46 dBm **SSC:** 18 dBm
Minimum distance between 2 nodes	Macro – UE: 35 m Macro – small cell cluster center: 105 m
Number of UEs	50 per licensed band carrier 10 UEs per unlicensed band carrier
Mobile Station	
Mobility type	Static
UE antenna height	1.5 m
Max UE TX power	23 dBm
UE antenna gain	0 dB
Channel Propagation Model	
Path loss model	**Licensed-Urban** • Macro cell UE to macro cell BS: ITU UMa • Macro cell UE to small cell BS: Winner II-C2 **Licensed-Suburban** • Macro cell UE to macro cell BS: Cost-231 Hata • Macro cell UE to small cell BS: Winner II-C1 **Unlicensed:** Industrial Indoor Channel
Number of MTC devices	20
Wi-Fi	
Wi-Fi standard	802.11n
Number of Wi-Fi STA	1

4.6 Simulation Platform

This research will be simulated on MATLAB software.

4.7 Simulation Results and Discussions

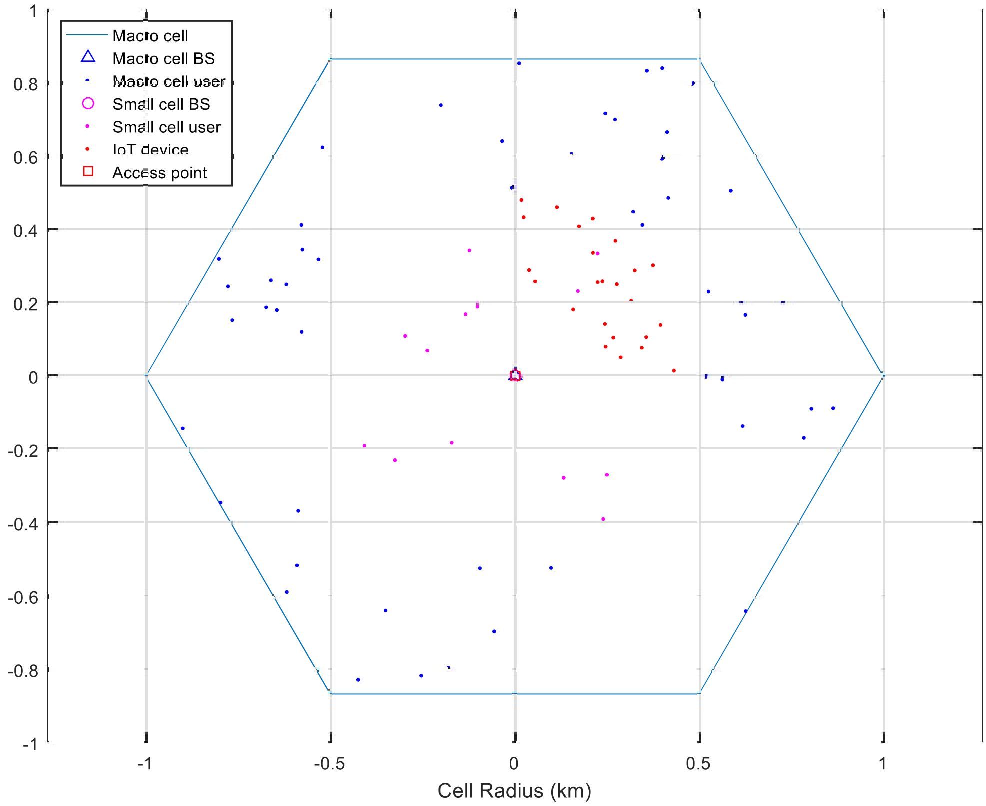

Figure 4.7 User distribution in heterogeneous network layout

From Figure 4.7, we can see that there are three networks in heterogeneous networks, such as macro cell denoted by blue triangle, small cell denoted by magenta circle and Wi-Fi networks denoted by red square. All networks, including macro cell BS, small cell BS and Wi-Fi access point are located in the centre of hexagonal grid. In the heterogeneous network, there are many kind of user and equipment, such as macro cell users denoted by blue points, small cell users denoted by magenta points, and IoT devices denoted by red points. Wi-Fi is used to provide service for IoT devices. Small cell users and IoT devices are distributed in the center of the hexagonal near to the Wi-Fi or access point and small cell BS, meanwhile macro cell users are distributed at the edge of the macro cell. Macro cell as the Primary Component Carrier (PCC) and small cell as the Secondary Component Carrier (SCC). Edge cell and small cell users use 2 GHz and 5.2 GHz of frequency respectively when they want build a communication to other.

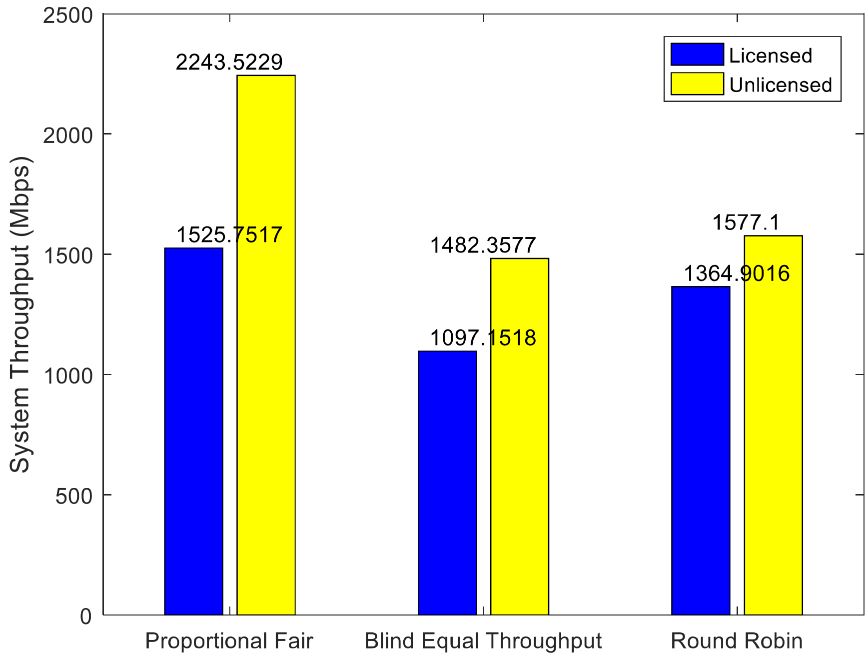

Figure 4.8 System throughput comparison of different scheduler

Figure 4.8 shows system throughput comparison using different scheduler, there are Proportional Fair (PF), Blind Equal Throughput (BET) and Round Robin (RR). Among three kinds of scheduler, PF achieves the highest throughput both in licensed and unlicensed band. The reason is because PF takes into account of CQI, while RR and BET do not. PF scheduler gives benefit for users who close to the eNodeB because their SINR is higher than edge users. The closer users also may be scheduled often than other users. But, edge users may have small probability to be scheduled, therefore it leads starving and low throughput for edge users. For RR scheduler, offers great fairness among users because all users will be given in equally amount of resource neglecting their channel condition, hence the system throughput became lower. BET scheduler will allocate a different number of PRBs based on their priority result without taking CQI into consideration. Users who has lower throughput have bigger probability to be scheduled until the throughput is not being the lowest anymore than other user's throughput. Therefore, BET also leads lower system throughput. In addition, comparing between licensed and unlicensed, system throughput in unlicensed band achieves higher than in licensed band. This result may because of the feature of carrier aggregation in unlicensed band and the position of users in the unlicensed band is closer to the eNodeB than user's position of licensed band at the edge of the macro cell. In addition, smaller number of network users are attained higher throughput because there are more resources in the network to assigned.

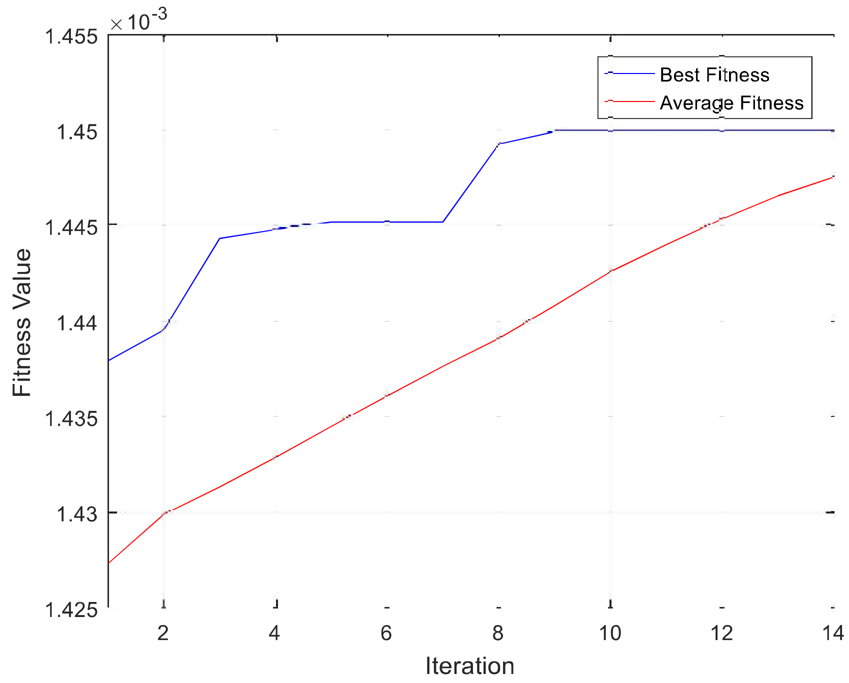

Figure 4.9 Fitness graph of GA in every iteration

Table 4.7 Convergence speed comparison between Taguchi and GA

	Taguchi	**GA**
Number of iterations	1	9
Running time	0.356 seconds	1.82 seconds

We also evaluate the performance between Taguchi's method and Genetic Algorithm (GA). Evaluation of GA is captured in Figure 4.9 and the convergence speed comparison between Taguchi and GA is noted in Table 4.7. The result shows Taguchi's method performs better than GA. The reason is because Taguchi uses orthogonal arrays could find the global optima quickly and does not utilize any steps like GA. Compared to GA, Taguchi's method can be used to analyze many different parameters without require high amount of experiments. This method only need fewer experiments to give the result about the effect of different variable levels of various factors and determine the best combination parameter value to improve quality. While, in GA using random initialization, thus there is no guarantee in achieving global optima. Furthermore, the fitness function, crossover and mutation rate of GA should be determined properly, because infeasible value can decrease the performance, eventually the optimum value could not be met. The convergence speed of GA is slower than Taguchi's method because we have to train the algorithm by trial and error until the optimum value is obtained. In our case, the convergence in GA is achieved at the ninth iteration. Moreover, the running time of GA is longer than Taguchi because in GA requires some steps to finish the algorithm.

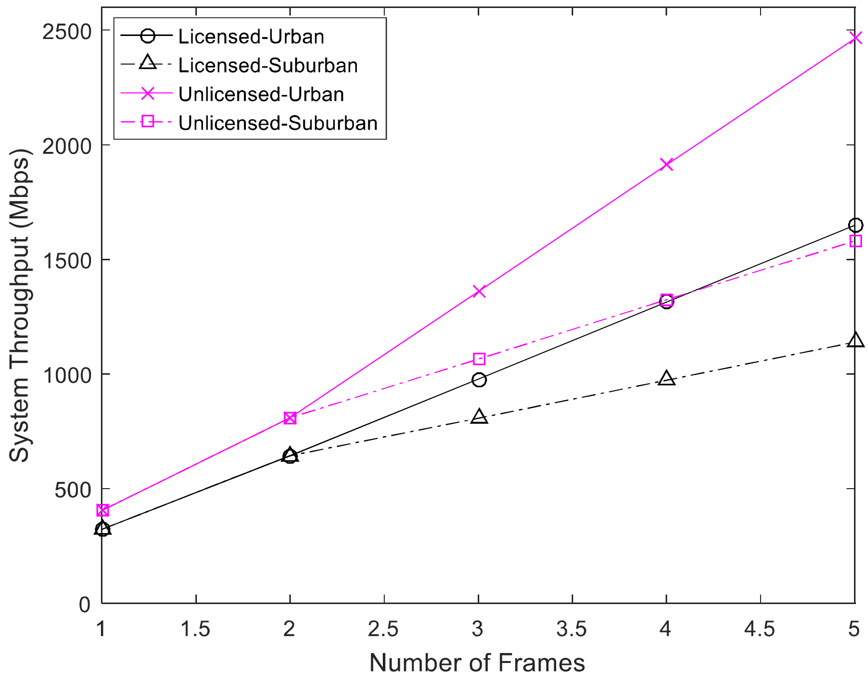

Figure 4.10 System throughput comparison of different environment using PF scheduler

When we compare the throughput results with urban and suburban environment, it is obviously seen on the Figure 4.10 that throughput results of suburban environment is lower than urban environment.

CHAPTER 5
CONCLUSION

After we observed and analyzed about system throughput, according to the simulation results, comparing with RR and BET scheduler, PF is the optimum scheduler can be used both in unlicensed and licensed band. Both small cell and macro cell users have benefit of the usage of PF scheduler because higher system throughput is achieved. The user equipments are using FBE-based mechanism was shown as the access method for LTE-LAA network in the unlicensed band. FBE-based LBT may be a problem when all networks are coexistence because they should wait for long time to occupy the channel. In this study, we only considered one frame period and bandwidth size. On the other hand, compare to the evolutionary algorithm, namely Genetic Algorithm (GA), Taguchi's method is an optimum algorithm for resource scheduling case both in licensed and unlicensed band.

Throughout this research, we mainly focused on the system throughput between the LTE-A in licensed and unlicensed by only considering resource allocation. Also, this work is limited to Taguchi method compare to Genetic Algorithm. For the future work, we can consider to observe the difference number of users, both in licensed and unlicensed, and compare with other access mechanism, such as Load Based Equipment-based LBT (LBE).

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