Addressing Load balancing Issues Related to Elastic Cloud Using Biomimetic Algorithms

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Abstract – **In business world, competitors use innovative approaches to improve their performance and profits. Cloud computing is one of these innovative approaches that have allowed many companies to further take advantage of their potential. Cloud computing is assisting companies to execute their business plans more efficiently, thus providing them with an advantage over their competitors.**

Despite the benefits that cloud could offer, various challenges exist in this field. Load balancing and cloud performance are two examples of such challenges. This paper aims to discuss some of these challenges and how biomimetic algorithm could be employed to address them. Our approach is inspired by load regulation occurring in nature; more precisely, in human body.

Keywords – Cloud Computing, Load balancing, Biomimetic Algorithm

I. INTRODUCTION

Rapid improvement in today's technologies enabled businesses to grow more quickly. Cloud computing as one of the new emerging technologies, provides real time services for enterprises, without binding them to their organizations [1]. Accessing to the Internet with any devices that can connect to the Internet, authorized businesses to access their information at any time [2]. As an example, Dropbox is one of these popular services that will accredit access to information while it can be easily synchronized and updated at any time.

By applying the virtualization techniques, cloud providers can minimize the costs of resource management process [3].
As demonstrated by other researchers, cloud users can pay fees to access multiple resources at any time, especially in their peak hours, which will help them to grow more quickly and stand out among their competitors [4].
The next section will debate on some challenges associated within cloud computing, applied in businesses.

II. DEBATABLE ISSUES IN CLOUD COMPUTING

A. Resource Availability
The ambition of businesses is to give efficient services to their clients; this fact will only be applicable if their resources can be available all the times.

As mentioned above, cloud computing will bring the opportunity of handling shared resources, which will reduce the associated costs and expenses. Gupta [2] mentioned that there is no need to estimate how many recourses will be required upon forming the business. Also as cloud is offering on demand resources, they can easily add more nodes to their networks, which will clarify the meaning of scalability in businesses [1]. Brynjolfsson, et al [5], however; argued that although scalability will enable the businesses to add more resources to fulfill their requirements, it does not guarantee that more resources would result in more services. Availability of the resources will allow the businesses to deliver right services to satisfy their customers, which will add more credits to their reputation as well.
Chunlan et al[6] uses the water and electricity resources of a country as an example to elaborate on the "availability" concept in cloud computing. Occasional outages can result in interruption of supplied water or electricity to the residents. Likewise, recourses provided by cloud computing, cannot be completely relied upon, as technical issues may cause unavailability of such resources. In 2009, Amazon lost the availability of the its resources for about 6 hours, which caused the customers to suffer from that issue even after two days [4]. Moreover, problems with networks and Internet connections can affect resource availability of the cloud, which will result in losing accessibility to the information [7].
The solution given by different authors is mainly focused on service level agreement. Dillon [8] pointed out that signing the SLA, cloud providers would be responsible to guarantee their resources availability. As Habib [9] discusses there is, however, no special standard for documenting theSLAs . Also, lack of information that businesses have regarding their down time tolerance created many challenges by fading the importance of SLA. Therefore, organizing the SLA, by reviewing and mentioning different features of availability, will enable the businesses to increase the percentage of available resources and guarantee delivery of services to their clients at any time.

B. Performance and Bandwidth Requirements
Critical to the usage of services in cloud computing, bandwidth is playing a major role in facilitating the access to different applications [10]. Bandwidth requirement is essential

in gaining the most benefits from cloud computing, whether using cloud for opening a simple email or using other services delivered by cloud providers. Brynjolfsson [5] mentions that bandwidth requirement is the fundamental point of supporting performance of the cloud. Yi [10], however, argues that the high price associated with bandwidth made the companies close their eyes on this important point and deliver services with acute latency to unsatisfied customers. Dahbur [11] discussed that most of the cloud providers want to deliver the services with low price, but with high performance. Neglecting the idea of using the shared resources, especially in peak hours of usage, will cause the customers experience a poor performance within the delivered services. Therefore, [1] suggests that to minimize the bandwidth costs, data management to adjust the data accessibility should be considered. Also, Gupta [2] notices that the network optimization in both cloud providers and cloud users is essential. An optimized Internet pipeline will help the cloud users to access their relevant application with high performance.

III. ADDRESSING THE CHALLENGE OF LOAD BALANCING

According to the literature discussed in previous sections, the main cause of challenges in cloud computing is related to load balancing techniques.

Several algorithms have been proposed so far addressing various issues of the load balancing in the cloud. In our research, we are proposing a new algorithm, inspired by the nature, focusing on biomimetic algorithms.

Tanya [12] believes that nature is a great encyclopedia for technology. Most of the clever technologies were inspired by the nature. The objective is to indicate the possibilities offered by a bio-inspired design approach in the solution of many technological issues. Designing the simple velcore is inspired by the plant bars attached to the dog's hair. The idea of lights reflection technology in LCD TVs originated from the design of butterfly wings. Similarly, this research is trying to model the solutions that nature provides for the issues; also known as biomimetic.

Endocrine algorithm and Spring Tensor Model are proposed as the biomimetic solution for solving the load balancing issues in cloud computing

A) Endocrine algorithm

. Endocrine glands are playing an important role in functionality of the endocrine systems. Hormonal regulation is managed by endocrine glands. Different algorithms have been proposed to explain the hormonal communication in human's body. But most of them are highlighting the feedbacking method, as the main communication process of hormones. "Figure 1" is depicting the hormonal reactions in endocrine systems. The motivation of this research is to model the regulation process of these hormones, based on their communication.
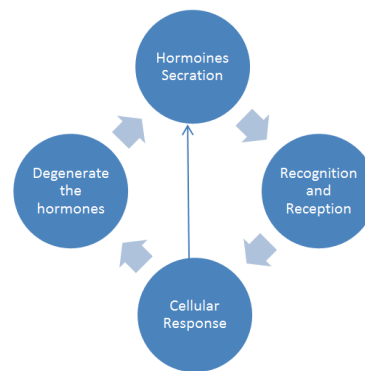

Figure 1- Endocrine feed backing procedure

B. Spring Tensor Algorithm

Spring Tensor algorithm emphasizes on predicting the direction and magnitude of the data load on each network nodes. This model will be adopted to plan, monitor (meter), manage and mitigate usage of the cloud computing resources and services seen as an elastic network (mass-sprin\g model) made of nodes that are connected to its spatial neighbors by springs that are in constant interactions/motion (Fig. 2). The proposed approach should be seen in the context of barriers to cloud computing and as a search for better tools that can help to alleviate problems with network bandwidth and its elasticity. The main aim is to set potential research directions in the design of effective service and of resource usage monitoring technologies.
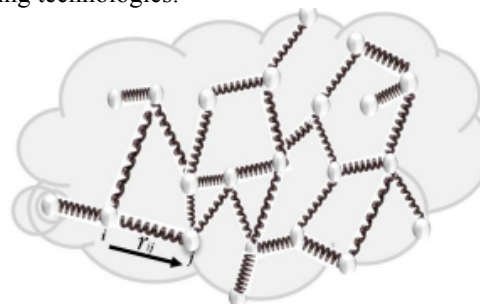

Figure 2-The model represent the elastic network. The relation between each resource is modelled with r. The spring tensor model will predict the direction and magnitude of the load on the network.

IV. CONCLUSION

The above discussed factors, determined load balancing as one of the inhibitors which needed to be addressed in future of cloud computing. Two different algorithm have been proposed as a solution of enhancing the load balancing techniques in cloud. The expected benefits of the technique are attributed to the fact that every resource (node) of the cloud can adjust its operation according to the current situation in its neighborhood, rather than strictly following some predefined topologies and data routing algorithms.

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Interference Mitigation in WBANS: Challenges and Existing solutions

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Abstract—Wireless Body Area Networks (WBANs) are an exciting new networking technology developed in the recent years with advancements in wireless communication, integrated circuits and Micro-Electro- Mechanical Systems (MEMs). They consist of a number of sensor nodes that are placed in or around the human body. However, their practical deployment requires addressing numerous challenges. WBANs face many stringent requirements in power, bandwidth, and network lifetime which need to be taken into serious consideration in the design of different protocols. In this paper, we investigate the importance of interference mitigation amongst coexisting Wireless Body Area Networks (WBANs). Since, a WBAN is most likely to encounter other WBANs, inter-WBAN interference and scheduling is of utmost importance.

Index Terms—Wireless Body Area Networks, IEEE 802.15.6, Interference Mitigation, Interference Avoidance

I. INTRODUCTION

Co-channel interference mitigation in WBANs is quite challenging due to the large density, high mobility and the unco-ordinated nature of WBANs. Interference can be larger than the signal even in cases where two WBANs are far from each other. This is logical because of the large variation of channel gain with body movement which implies the link strength is independent of the distance. The mobility of WBANs makes interference even more challenging as WBANs can move into each others range and result in a large density of people with their WBANs in each others coexistence [1]. Coexistence has shown to provide much severe effects for higher data rates. Additionally, in most application WBANs are rational and self-interested which means they do not cooperate with each other to make power decisions that implies each WBAN independently chooses its transmission power based on its belief of other WBANs' choice [2].

The most valuable resource of a WBAN is energy which can be easily wasted by inter-network interference which reduces the SINR value and leads to throughput degradation. In order to maintain the minimum acceptable link quality, the transmit power should be limited to minimize the interference level and save battery life [3]. Thus, interference mitigation schemes aim to decrease the average transmit power using link adaptation

mechanisms whilst maintaining link quality at the cost of lower data rate or throughput [3]. A total of 70% of the total power consumption of off-the-shelf sensor nodes is related to the transmission power of their wireless transceivers. This can be even more challenging in the case of WBANs as battery replacement or recharging can be quite uncomfortable [4]. The scarce constraint of energy in WBANs requires simple, robust, intelligent and light solutions for these networks to cope with the small processing power and small memory of their devices.

The IEEE 802.15.6 working group has defined new PHY and MAC layer proposals for WBANs that provides ultra-low power, low cost, low complexity and short range wireless communication in or around the human body. The proposed standard requires the system to function properly within the transmission range of up to 3 meters when up to 10 WBANs are co-located [5]. It also has to support 60 sensors in a $6m^3$ space (256 sensors in a $3m^3$ cube)[5]. Thus, there is a large possibility of interference amongst WBANs in each others coexistence. The interference link is most likely to be from a device on some other person (off-body) and the signal link is most likely between two devices on one person (on-body) [1]. In cases where the main source of channel dynamics is subject to movement since the two objects are not synchronised, signal and interference links are uncorrelated and statistically independent when considered over a large period of time in the order of 100's. Whilst, in cases where mobility is not the main reason for channel dynamics (over a short period of time), signal and interference links are correlated and display similar characteristics [6].

Unfortunately, interference mitigation schemes proposed for other networks cannot be deployed in WBANs because of the following differences. A WBAN mainly has more frequent topology changes and a higher moving speed whilst a WSN has static or low mobility scenarios. WBANs are similar to MANETs in terms of the moving topology with group-based movement rather than node-based movement. Thus, due to the group-based movement and high mobility nature of WBANs they are not similar to WSNs or MANETs which implies their interference mitigation approaches cannot be used for WBANs [7]. In addition, due to the limitations of WBANs in terms of cost, size and energy consumption, the function of each sensor node needs to be very simple. Thus, advanced

antenna techniques cannot be used for interference mitigation in WBANs [8]. Additionally, interference mitigation proposals for cellular networks cannot be deployed in WBANs due the following reasons. For one thing, power control is not convenient for WBANs due to their low energy consumption and simple structure whilst it is a feasible method in cellular networks. Additionally, the location of a mobile station is usually uniformly distributed in cellular networks whilst nodes in WBANs are deployed more densely. Also, neighbor networks in cellular networks adjoin with each other due to the network coverage requirement, whilst a gap between WBAN networks is acceptable to mitigate the mutual interference [8].

The rest of the paper is organized as follows. Section II describes Intra-WBAN and Inter-WBAN Interference. The interference mitigation schemes proposed thus far for WBANs are presented in Section III. Section IV concludes the paper.

II. INTRA-WBAN AND INTER-WBAN INTERFERENCE

Based on the proposed IEEE 802.15.6 standard, nodes in a single WBAN can avoid interference by using multiple access techniques such as time division [3]. Thus,interference is not an issue for intra-WBAN communication. Generally interference occurs when no-coordination exists amongst multiple WBANs that coexist in each other's vicinity [3]. In cases where co-located WBANs use the same channel (similar frequencies), transmissions can conflict; as the active periods can overlap [9]. Thus, WBANs operating at the same frequency should be synchronized. In [1], the performance of three multiple access schemes, namely CDMA, FDMA and TDMA for inter-network interference has been investigated using real-world interference measurements in terms of Bit Error Rate (BER), Statistics of signal to interference and noise ratio (SINR) and probability of collision. TDMA and FDMA have shown to be more efficient for interference mitigation whilst in the case of CDMA, WBANs have a high chance of collision as no set of codes can maintain orthogonality and may transmit over the same time and frequency in entirely asynchronous systems. TDMA has $N_c - 1$ (N_c refers to the number of orthogonal frequency channels) times shorter transmission time than FDMA for the same number of bits. Since, power consumption is important in WBANs, the lower the operating time the lower the overall power consumption. Most contention-based protocols that use CSMA/CA utilize Clear Channel Assessment (CCA) to specify the status of the channel. However, the high path loss inside and outside WBANs does not guarantee this approach [10]. Scheduled based approaches like TDMA are efficient for CCA problems and traffic correlation. However, as all sensors in TDMA approaches must receive periodic control packets to synchronize their clocks extra energy is consumed for their periodic synchronization [10].

Moreover, with the increase in the number of WBANs that can coexist in short proximity of each other, the communication link can suffer performance degradation. Even in cases where small number of WBANs are deployed in each other's vicinity, the received signal strength of the interfering signal can be quite high which affects the performance of a particular WBAN [3]. In fact, WBANs can practically either exchange information such as channel gain, interference and current transmission power or collect this information through their own measurements [2].

The sources of interference may be from co-existing WBAN networks or non-WBAN networks. A reasonable assumption is to consider the overall interference that appears at the intended receiver node as white which means the intended WBAN network being observed acts as a lognormal fading channel with additive white Gaussian noise. According to the standard, in cases where interference occurs, the packet can be retransmitted during a certain time period before being considered lost. However, there is a tradeoff between the throughput requirement and energy consumption [9]

Nodes in WBANs have stringent energy constraints and require low power techniques which can be achieved by an appropriate choice of the MAC as it has a key role in defining the energy consumption. However, the proposed MAC protocols have mainly focused on enhancing throughput, latency and bandwidth utilization whilst not considering the major requirement of energy conservation [10]. The superframe structure of the WBAN MAC is shown in Figure. 1 and consists of the following four periods: control period, Contention Access Period (CAP), Contention Free Period (CFP) and inactive period. CAP initiates after GTS requests and topology management and is controlled by the CSMA-CA algorithm. CFP initiates at the end of the CAP and consists of a number of Guaranteed Time Slots (GTS) which can be assigned by the coordinator to the sensors based on TDMA [9, 11]. Since all WBANs are considered to use similar superframe structures and inter-WBAN superframe synchronization is achieved before transmission, a collision never occurs between one WBAN's data frame and another WBAN's control frame. Whilst, interference can occur between different WBAN's data frames in the CFP [9]. A packet in the superframe can be lost either via *collision* or *buffer overflows*. Collisions occur in the GTS slot where no carrier sensing is available. Buffer overflows occur in cases where CSMA-CA delays the transmissions because of the non-free channel. Thus, CSMA/CA avoids collisions but fills the buffer whilst GTS does not avoid collision but does not fill the buffer [9].

Coexistence amongst WBANs mainly leads to *beacon loss* and *data loss*. Since beacon transmissions do not use carrier sensing, beacons of coexisting WBANs may collide with each other. In this case a beacon is lost; so the sensors lose synchronization and must not transmit in that superframe [12]. Depending on the mode of operation, data loss can occur when a number of WBANs coexist. For instance, life critical data require retransmission and acknowledgements. However, the lack of clear channel assessment and the inflexible nature of GTS approaches leads to inefficient consequences in the period of coexistence [12].
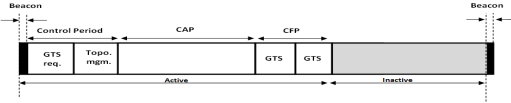
Fig. 1.   WBAN MAC

III. PROPOSED INTERFERENCE MITIGATION APPROACHES

The proposed scheme for interference mitigation in WBANs can be divided into two categories: 1) interference reduction techniques, 2) interference avoidance techniques. In interference reduction schemes, different devices are possibly transmitting at the same time, but with different power, modulation scheme, data rate or phase. The aim of these approaches is mainly to minimize the interference level at the receiver by optimizing the system parameters such as power, data rate and some other physical layer parameters. In interference avoidance techniques, the coordinators of different WBANs attempt to assign orthogonal channels to each device in the network, thus avoiding the interference with the cost of lower system throughput.

A. Interference Reduction Techniques

Efficient power control mechanisms are used to maintain the link quality (signal to interference noise ratio or strength level). More specifically, the power quality is controlled to suffice the desired link quality. This scenario is even worse in cases where interference is quite significant; for instance in cases where other coexisting wireless networks have a high transmit power. For instance in the case where the signal cannot be clearly recovered by the intended receiver, this approach will increase the power level of the relevant transmitter to adjust the required link quality whilst causing interference for other networks in its vicinity. Therefore, nodes at approximate WBANs also increase their transmit power which degrades the link quality at the intended receiver and no links would be able to operate with an acceptable quality. However this approach is not convenient for use in WBANs due to postural body movements and the mobility of nearby WBANs [3]. In [4], a dynamic power control mechanism using reinforcement learning is proposed for interference mitigation in WBANs.

One other approach is to use advanced signal processing techniques to cancel interference. However, this approach cannot be practically used in WBANs. For one thing, these interference mitigation methods require knowledge of the channel between the receiver and each of the interferers; whilst such a accurate estimation of the channel condition is very challenging in WBANs. Additionally, this approach requires a receiver with high computational complexity which is not practical in the case of WBANs with dense deployment of nodes, specially as most WBAN nodes are battery-driven and require prolonged lifetime for one's own comfort.

In [3], *adaptive modulation*, *adaptive data rate* and *adaptive duty cycle* are proposed towards interference mitigation in wireless body area networks. These method have low complexity which is convenient for use in WBANs due to their small size and low computational capability. An Interference Mitigation Factor (IMF) is also introduced to evaluate the performance of the proposed schemes which is defined as the reduction of the transmit power level obtained by using an interference mitigation method compared to the original operation mode. It is a function of channel condition and SINR [3]. However, implementation complexity has not been considered and the effectiveness of these schemes for multiple WBANs has not been investigated. For *adaptive modulation*, a set of MPSK schemes such as BPSK, QPSK and 8PSK can be used as they have the same detection mechanism at the receiver. With a pre-defined BER, the SINR can be obtained from the channel conditions. 8PSK is used to gain higher bit rate at higher SINR values, whilst QPSK can be used when the transmit power is between a certain threshold. BPSK is used in cases where SINR is lower than the lower threshold [3]. For *adaptive data rate*, the date rate is divided into a number of steps between its maximum (R_{max}) and minimum value (R_{min}). In the normal mode, the date rate operates at it maximum value and changes by comparing its target SINR and weighted sum of SINR values. The weighted sum may reduce the variations in the SINR. In terms of *adaptive duty cycle*, the duty cycle is divided into a number of steps between its maximum and minimum values. Normally, the duty cycle is set at its maximum value and changes by comparing its target SINR and its weighted sum of SINR.

In [2], a non-cooperative power control game is proposed for inter-network interference mitigation in WBANs. The proposed method aims to maximize the overall system throughput using the minimum power and applies a power pricing mechanism to minimize the transmission power of each user and maximizes the total transmission rate. An adaptive pricing mechanism is also proposed to dynamically adapt to changes in power budgets and channel gains; where the higher battery charge the lower the price associated to it. This way users with low power budgets and bad channel conditions are penalized whilst users with good channel conditions and high power budgets take advantage of their good conditions. As there are issues with accessing information regarding channel gain, their heavy cost and their overload on the system to measure it as well as exchanging it, the authors consider using variations in SINR which is less expensive and much suitable.

The authors in [13], proposed Interference Cancelation with Interrupted Transmission (ICIT) for a two-diversity branch receiver. ICIT uses the amplitude and phase of the interference known at one instance to combine the two received signals such that the interference signal at one branch is equal and out of phase at the other branch. In this approach, a predefined algorithm switches the desired signal off at regular intervals. Therefore, the amplitude and phase of the two interfering signals have to be calculated at the two receiving antennas. Thus, the desired signal transmitter is switched off at regular intervals which implies that at a certain distance only the phase and amplitude of the interference signal is measured. This value is then used to calculate the a weight vector for the next time interval until the required signal is interrupted.

B. Interference Avoidance Techniques

Channel switching can be used as an approach towards interference mitigation in WBANs in cases where the amount of non-overlapping channels is higher than the number of coexisting WBANs so that a unique channel is assigned to each WBAN [9]. IEEE 802.15.4 has 16 non-overlapping channels at 2.4 GHz. Thus, switching is a convenient approach in this frequency and 16 WBANs can coexist with each other at this frequency. However, Bluetooth or IEEE 802.11 (WiFi) reduce the available interference-free channels.

In [7], a random incomplete coloring (RIC) with high spatial reuse and low complexity has been proposed for interference mitigation in WBANs, where interference avoidance is modeled as a graph coloring problem. This approach allows for higher spatial reuse than when a minimum of k colors are used by allowing partial vertices to be left uncolored. The uncolored nodes represent nodes with no transmissions which implies no interference. Therefore, a subgraph of the main graph can be colored excluding the uncolored vertices. For data transmission, first the coordinator of the WBAN negotiates with other WBANs that are in its interfering range and assigns reserved resources to them accordingly. The end nodes of the WBAN only wake up when receiving beacon messages that carry the preregularized transmission schedule of the coordinator or when transmitting vital signals following the schedule towards the coordinator.

In [10], a traffic adaptive MAC protocol,namely (TaMAC) is proposed for WBANs which considers the traffic information of nodes in WBANs and the coordinator adjusts the duty cycle of the nodes based on their traffic pattern. Therefore, nodes with low duty cycles need not receive frequent synchronization and control packets if they do not any data to send transmit or receive. TaMAC aims to provide real-time health monitoring, tolerable delay, scalability, low power consumption, collision free transmission with TDMA and desirable QoS for all types of traffic. It classifies the traffic into normal, emergency traffic and on-demand. TaMAC uses two channel access mechanisms based on the type of the traffic, where a wakeup radio mechanism is used to reliably accommodate on-demand and emergency events and a traffic-based wakeup mechanism is used for emergency and on-demand traffic. This suffices the low energy consumption requirements of WBANs as it uses a separate control channel together with the data channel. A traffic-based wakeup table is built that stores the ID and traffic pattern of all the nodes. Thus, the nodes remain asleep unless they need to send or receive data. When two nodes have the same traffic pattern, resources are allocated to the node with the higher priority. In cases where two nodes have the same traffic pattern and the same priority, resources are allocated to the node with minimum data volume. This protocol has shown to outperform SMAC, 802.15.4 MAC and WiseMAC protocols in terms of delay and power consumption.

C. Brief Comparison

In comparison, interference avoidance schemes can achieve a higher SINR level compared to interference reduction schemes, but their throughput is usually lower. Moreover, in terms of computational complexity, interference avoidance techniques requires less complex receivers but extra cooperation between coordinators is inevitable. In interference reduction schemes, the receiver has a more complex decoder because it needs to decode several messages with different levels of SINR, data rate and power; but since cooperation is not performed between coordinators lower transmission overhead can be achieved by these approaches.

IV. Conclusion

In this paper we have presented the challenges of deploying multiple WBANs in each others vicinity and the interference mitigation schemes proposed thus far for WBANs. Some of the challenges of WBANs have been considered in these proposals however; their practical deployment requires further research and investigation. The future vision of WBANs is to allow for reliable, cost-effective and energy efficient communication amongst all co-located WBANs.

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A Proposal for an Enhanced Inter-Cell Interference Coordination Scheme with Cell Range Expansion in LTE-A Heterogeneous Networks

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Abstract- In heterogeneous network, the interference situations may be changed in different locations because of nodes with different powers as well as traffic loads. The Inter-Cell Interference (ICI) problem can occur for both data and control channels. To mitigate ICI problem, enhanced Inter-Cell Interference Coordination (eICIC) techniques are proposed in the Long Term Evolution-Advanced (LTE-A) networks particularly picocells. Moreover, the coverage areas of picocell are usually narrow because of difference between transmission power of macro eNodeB (eNB) and pico eNB. Therefore, traffic load is distributed unequally which can lead to macrocells overloading. To address the coverage problems resulted by nodes with different powers, Cell Range expansion (CRE) technique has been recently proposed. In this paper, the CRE approach is combined with eICIC-time domain scheme to improve system performance using features of both two techniques.

Keywords- LTE-Advanced, HetNet, picocell, cell range expansion, enhanced intercell interference coordination.

I. INTRODUCTION

In recent years, the demand for mobile broadband services with higher data rates and various types of Quality of Service (QoS) is growing rapidly. This demand has motivated 3GPP to work on Long Term Evolution (LTE) to achieve the peak data rates more than 100 Mb/s, a radio-network delay of less than 5 ms, the enhanced spectrum efficiency and the bandwidth flexibility. Although LTE Release 8 has many of the features taken into account for future fourth generation (4G) systems [1], the performance of LTE Release 8 does not meet IMT-Advanced requirements defined by the International Telecommunications Union (ITU) for the 4G evolution [2]; therefore other releases have been introduced. The evolved versions (LTE Release 10 and beyond), called LTE-Advanced, can meet the requirements defined by IMT-Advanced (e.g., downlink data rates up to 1 Gbps) [3].

Since the radio bandwidth is one of the scarce resources in wireless networks, new resource allocation algorithms should be introduced to overcome radio resource limitation particularly when applications with high data rate are deployed. For this purpose, the frequency reuse technique is applied to cellular networks to increase the system capacity. However, the system performance is severely degraded because the interference increases when system uses the frequency reuse factor one. In frequency reuse one all cells use the same frequency band. Intercell interference (ICI) resulted by using the same frequency in neighbouring cells can restrict the 4G performance in terms of throughput and spectral efficiency. Therefore, the ICI mitigation is a critical point to improve the performance of LTE and LTE-A networks.

In this paper, we study ICI challenges in LTE-A particularly picocells. Picocells are one of the important solutions among low power nodes because they can be efficiently deployed in local regions with high volume traffic (such as hotspots) and improve the overall system capacity. Therefore, the important roles of macrocell and picocell in 4G network motivated us to study the ICI problem between macrocell-picocell and then proposed a new eICIC scheme to improve the system performance.

The rest of the paper is organized as follows. The heterogeneous architecture will be reviewed in Section II. The challenges of macrocell-picocell scenario are underlined in Section III. Section IV introduces the Cell Range Expansion technique. A comprehensive survey of picocell eICIC-time domain schemes is depicted in Section V. Section VI proposed a new eICIC scheme. The conclusion is given in the final Section.

II. HETEROGENEOUS ARCHITECTURE

Since data traffic demand in cellular networks is growing exponentially, further improvements in 4G spectral efficiency could be possible by increase of the node densities. However, with current dense deployments, the cell dividing gains are considerably decreased because of severe ICI. Moreover, site acquisition costs can get prohibitively expensive particularly in a space limited dense in urban region [4]. One solution to overcome this issue is the utilization of heterogeneous network (HetNet).

A HetNet consists of macrocells as well as low power nodes (i.e., femto, pico, relay nodes) which can be classified in terms of their transmission powers, antenna heights, the type of access mode provided for UEs, and the backhaul connection to other cells [5], [6]. The goal of using low power nodes is to offload the traffic from the macrocells, enhance coverage and throughput, and increase the spectral efficiency by spatial reuse of spectrum. Picocell is one of the important solutions which can be deployed efficiently in local regions with high volume of traffic (such as hotspots)

and improves the overall system capacity [7]. Picocells are used with lower transmission power rather than macrocells (in a range from 23 to 30 dBm) [8, 9]. Since picocells usually work in open access mode then all users can access them. In general, the open access mode means that any user in the network can automatically connect to the hotspots. Picocells are used to improve capacity as well as the coverage of outdoor or indoor regions in environments with inadequate macro penetration. Moreover, the communication between macrocells and picocells is done over the X2 interface.

III. CHALLENGES OF MACROCELL-PICOCELL SCENARIO

Using nodes with different transmission powers comes up new challenges in HetNets. In this section, we will describe two important cases of these challenges in macrocell-picocell scenario.

A. Intercell Interference Problem

When a UE moves away from the serving eNB and becomes closer to other eNBs, the strength of desired received signal decreases and the ICI increases. The impact of ICI in LTE downlink can be analysed according to the received signal to interference and noise ratio (SINR) of UEm on RBn. Three important factors have a great influence on the SINR of each UE including: (a) Channel gain from eNB to UE, (b)Transmission power of each RB, and (c) RB allocation scheme.

Because of the larger transmission power of the macro eNB, the handover boundary becomes closer to the pico eNB which causes uplink interference challenges. When a UE closed to picocell is served by macro eNB, the strong interference will occur for UE located in the picocells. Consequently, picocells may become underutilized because of the large impacted interference. Moreover, it is clear that a mechanism is needed to allow flexible connection between a serving eNB and a UE and mitigate downlink and uplink interference beneficially [4]. Therefore, one of the important aspects of HetNets is interference management. The interference management should be able to support sufficiently the co-channel deployment of various traffic loads as well as using of different numbers of low power nodes at different geographical regions. In order to coordinate between macro eNB and pico eNB, some messages should be exchanged among them through X2 interface [10].

B. Imbalanced Coverage

Using nodes with different powers can lead to other challenges such as imbalanced coverage between uplink and downlink. The downlink coverage of the macro eNB is much larger than the coverage of the pico eNBs because of difference in their transmission powers. However, the difference in the transmission power of macrocell and picocells does not affect the coverage in the uplink because in this case the UE is a transmitter and the transmission powers of all UEs are same. Therefore, the eNB that provides the best downlink coverage might be different from the eNB providing best uplink coverage.

IV. CELL RANGE EXPANSION

In the traditional cell selection method, UEs can select the serving cell by comparing a downlink signal from macro eNBs and pico eNBs called Reference Signal Received Power (RSRP). Then, the cell with higher RSRP is selected as a serving cell. This technique is called max RSRP. However, in HetNets, cell selection based on the strongest downlink RSRP is not the best strategy because UEs connect to a higher power node instead of the lower power nodes at the shortest pathloss distance. Therefore, traffic load is distributed unequally which can lead to macrocells overloading. Moreover, the maximum RSRP method causes a sever uplink interference between macro UEs and pico UEs [11]. Consequently, to address the problems resulted by nodes with different power, new cell selection techniques are required so that the UE connects to cells with a weaker RSRP.

One solution is that an offset value is added to RSRP received from pico eNB so that the UE preferentially selects a pico eNB as the serving cell even when it is not the strongest cell. This technique is known as Cell Range Expansion (CRE). Note that the range expanded area is an area around picocells where UEs connect to pico eNBs because of receiving RSRP plus an offset value. Different offset value ranged from 0 to 20 dB can be considered and for the offset value equals to 0, CRE acts as the maximum RSRP technique. However, if the offset value is not selected sufficiently for CRE, the enhancement of network performance cannot compensate the cost of using picocells. Consequently, the offset value should be determined precisely to achieve a good system performance.

Although the CRE significantly mitigates interference in the uplink, the downlink signal quality of UEs located in the range expanded area decreases. Such UEs may suffer from downlink SINRs below 0 dB because they are connected to cells that do not have the best downlink RSRP [11]. Therefore, in the range expanded area, both data and control channels will suffer from ICI because they are not planned for too low SINR. Consequently, ICI mitigation methods should be deployed for control and data channel in CRE approach to keep the cell coverage and improve the system performance.

## V. ENHANCED INTERCELL INTERFERENCE COORDINATION ALGORITHMS FOR PICOCELL IN LTE-A

In HetNet, the interference situations may be changed in different locations because of different powers as well as traffic loads. The ICI problem can occur for both data and control channels in range expanded areas. Although in 3GPP, the interference of data channel can be mitigated through ICI mitigation techniques proposed for LTE Release 8, the suggested ICI mitigation methods did not consider the problem of control channel interference. Therefore, in order to keep the cell coverage and improve the system performance, ICI mitigation should be deployed for control and data channel in CRE approach. Moreover, due to small radius of picocells, the LTE ICI mitigation

schemes such as the fractional frequency reuse based scheme cannot be used. Therefore, to overcome the ICI problem in LTE-A, enhanced Inter-Cell Interference Coordination (eICIC) techniques have recently been proposed and can be divided into three major categories [12]: Time domain, Frequency domain and Power domain. Since the focus of this paper is time-domain, therefore a number of time domain-eICIC techniques proposed for macrocell-picocell configuration are reviewed as follows.

If interference coordination is not deployed for UEs located in range expanded area, they will experience large downlink interference from the macro eNB. The interference problem can be mitigated in time domain through subframe utilization. This utilization is PERFORMED across different cells through protected subframes (PSF) including almost blank subframes (ABS) and reduced power subframes (RPS). ABSs are subframes without any activity [13] or only transmitting the reference signals from macro eNB without any types of control or data signals while in RPS the macro eNBs only decrease the transmission power on the specified subframes. Macrocell-picocell configuration use ABSs at the macrocell and schedule UEs located in the range expanded area within subframes that overlap with the ABSs of the macrocell as shown in figure 1. ABS configuration illustrates how picocells are informed about the interference pattern from the macro eNB and then schedule their UEs on protected subframes to avoid from high power interference. Although the large number of ABSs can reduce the interference and improve the performance of picocell, it will decrease the available transmission time for macrocell. Therefore, the number of ABSs should be selected properly to improve the whole system performance.

Reference [7] investigated the performance of eICIC and CRE in picocell downlink system. In this algorithm, only the macrocell does not transmit on some subframes (protected subframes) for the specific time to protect UEs connected to the picocells because the interference caused by the picocells is not important in a HetNet. Then macrocell uses other resources (non-protected subframes) to send data to its UEs. The ratio of the protected subframes is obtained based on the number of the UEs connected to the picocells without CRE, and the number of the UEs connected to the picocells with CRE. Reference [14] has considered a non-static eICIC scheme using Lightly Loaded CCH transmission Subframe (LLCS). To mitigate the Physical Downlink Control Channels (PDCCH) interference impacted from the macrocell to the pico CEUs, the proposed algorithm deploys both LLCS and ABS just to the macrocells. Since PDCCH is distributed according to the predetermined hopping pattern over the CCH area, the interference of PDCCH in neighbour cells can be mitigated by the LLCS.

Reference [15] proposed a method to find the optimal amount of ABS in ABS configuration. This algorithm has assumed that pico UEs are categorized into victim UEs and normal UEs. Moreover, macro eNB works only in non-ABS but pico eNB performs in all subframes and victim UEs are scheduled in ABSs. The optimal selection for victim UEs
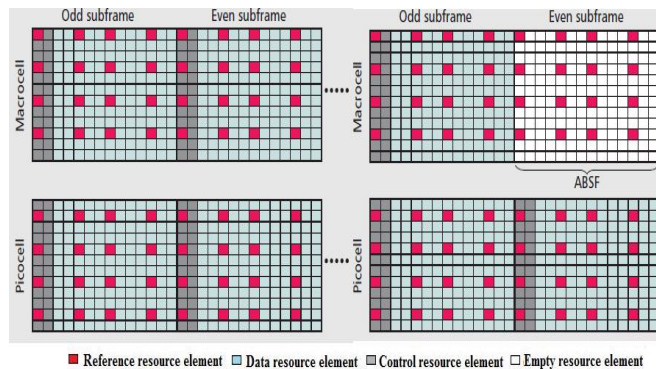
Figure 1: ABSs configuration deployed in time domain eICIC for 3GPP heterogeneous networks:
a) Macrocell and picocell subframes without any eICIC, b) Macrocell and picocell subframes with eICIC

and normal UEs is done through the utility function. In [16], two interacting factors have been considered to improve the performance of macrocells and picocells: UE partition and the number of ABSs. A Nash Bargaining Solution [17], [18] has been used to model the UE partition problem. The ABS pattern will be generated based on the obtained subframe ratio and then broadcasted to all eNBs. Reference [19] investigated the effect of static and dynamic protected subframes (PSF) configuration on system performance. A dynamic scheme is used to determine the PSF density (i.e., number of PSF). Therefore, a new metric has been deployed (based on average logarithmic throughput of the macrocell and picocell UEs) to find the suitable PSF density because the low PSF density decreases the performance of pico UEs.

Channel Quality Indicator (CQI) adjustment is another problem which should be taken into account when ABSs are used. Due to the time delay in CQI reporting, it is possible the CQI measured for one type of subframes is deployed for another type of subframes. Therefore, the channel cannot be appropriately estimated and then a wrong modulation and Coding Scheme (MCS) will be selected. Consequently, using incorrect CQI leads to transmission failure or transmission inefficiency. References [20] and [21] worked on CQI adjustment to improve the UE performance. For instance, in [20] the multiple CQI feedback has been used along with the joint decision method. For this purpose, a set of K neighbouring macro and pico eNBs cooperate to select the status of each other.

As a conclusion for the time domain schemes, the interference is mitigated when victim UEs are scheduled on the protected subframes and non protected subframes. When the CRE offset value is low, a small number of UEs connects to the picocells. Consequently, the cell edge throughput becomes higher when the ratio of the subframes allocated to picocell is low since many UEs connected to the macrocell can use more resources. However, when the high CRE offset value is used, a large number of UEs are offloaded and then connect to the picocells. Therefore, the high ratio of the picocells' subframes is required to improve

the cell edge throughput. On the other hand, the cell throughput decreases by increasing the CRE offset value because the picocell throughput decreases when the UEs far from the picocells are connected to the picocells. Consequently, in time domain eICIC techniques, the ratio of subframes selected for the macrocell-picocell configuration is very crucial factor and an inappropriate ratio can sacrifice the cell edge throughput or cell throughput. Consequently, approaches with a dynamic subframe ratio selection have better performance among proposed time domain eICIC techniques.

VI. THE PROPOSED SCHEME

As discussed in previous sections, although the CRE can mitigate interference in uplink, it can lead to interference in downlink for UEs located in cell range expanded area (RE UE). Especially if the offset value is not selected efficiency, the system performance is degraded in case of using CRE. However, if the CRE technique is combined with one time domain eICIC scheme, it can improve the system performance. This is because when the number of UEs located in cell expanded area can be matched with the number of ABSs, the interference between RE UE and macro UE can be mitigated.

For this purpose, we propose a technique which combines CRE with ABSs scheme. In this scheme, the offset value and ABS ratio can be determined simultaneously based on some metrics such as the throughputs and outage. These metrics are the input of the system and they will be calculated every Time Transmission Interval (e.g., 1 ms). The cell monitors the inputs and then makes decision about the next value for offset value and ABS ratio. To find the optimal value for ABS ratio and offset value, an optimization technique is needed.

Another feature of the proposed scheme is that each macro cell can execute it independently based on its performance.

Assessment is based on the MATLAB system level simulation in a LTE downlink network with 19 cells. The network topology is composed of a set of cells and network nodes including macro eNBs, pico eNBs and UEs which are distributed within cells. A certain area is defined for simulation where the eNBs and UEs are located and only in this region, UE movement and transmission are simulated. Each network node is identified by a unique ID and its position is defined using Cartesian system. A wraparound function should be used to make sure that the users do not exit from the simulation area. The simulation length is measured by TTIs which equals 1 ms.

VII. CONCLUSION

To overcome the ICI problem in macrocell-picocell, several eICIC techniques have recently been proposed for time domain. Approaches with a dynamic subframe ratio selection have better performance among proposed time domain eICIC techniques. To enhance the performance of system, we proposed a scheme combining CRE and ABSs scheme. By this scheme, the offset value and ABS ratio can

be selected simultaneously based on system throughputs which can lead to improve the system performance.

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A Case Study for Choosing Proper Relocation Algorithms to Recover Large Scale Coverage Hole(s) in Wireless Sensor Networks

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Abstract—Coverage holes as large scale en mass and correlated node failures in wireless sensor networks, not only disturb the normal operation and functionality of networks, but also may endanger network's integrity. Recent trends to use relocation of currently deployed nodes have attracted attention especially where manual addition of nodes are neither feasible nor economical in many applications. The transition from centralized to distributed node relocation algorithm gradually paves away for applications in which nodes are deployed in harsh and hostile environments in absence of central supervision and control. Although, many different relocation algorithms have been devised to address their given applications' challenges and requirements and they are efficient in reaching their design goals, they may not be similarly responsive to unpredicted and different circumstances may occur in the network. This paper, demonstrates one of such case, DSSA (Distributed Self-Spreading Algorithm) that is mainly applied for balancing node deployments and recovery of small coverage holes. It is shown here that DSSA is not able to fully recover large scale coverage holes even if all nodes participate in recovery process and relocate with sufficient number of iterations.

I. INTRODUCTION

With constant advancements in sensor nodes, wireless sensor networks (WSNs) [1], [2] have been adapted for many applications [3]–[9] especially in harsh and hostile environment where there is lack of centralized supervision and control. With increasing flexibility and ubiquity (i.e. in structures [10], underground [11], in the air [12], underwater [13], or on the surface of sea [14]) come new challenges and design requirements which should be properly addressed in wireless sensor networks in their designated applications. *Coverage holes (CHs)* as en masse and correlated failures of deployed sensor nodes [15] as the result of battery exhaustion or physical damages [16] is one of prevalent issues which should be dealt with accordingly, otherwise they not only disturb the normal operation of network but also jeopardize the integrity of whole network if they remain unattended at their occurrences.

Benefiting from controlled mobility of nodes [17], [18], relocation of currently deployed nodes are used to recover the coverage holes and unbalanced network formations seems

to be promising solution especially where neither centralized control nor manually addition of nodes deem feasible. Thus, to properly exploit available redundancy of deployed nodes, many relocation algorithms have been introduced in order to repair and make network more flexible and robust in failure-prone environments with the harsh and hostile conditions.

In spite of recent advancements in batteries and energy-Scavenging technologies and distributed relocation algorithms, physical movements especially in autonomous nodes, consume majority of nodes' energy. Inspired by the nature [19], many relocation algorithms devised [18] to address the emerging challenges caused by transition from centralized to distributed control of network and to make objective movements of node movements more practical and implementable in large scale networks. Although the distributed relocation algorithms mainly evolved by reducing the consumed energy of nodes, they may not be similarly efficient and responsive to unpredictable events and circumstances which may occur in the network and are not accounted for in the relocation algorithms. In this paper, it is shown that although DSSA relocation algorithm is rather efficient to repair and recover small coverage holes and to balance network formations, it is not a proper choice as it is not able to properly recover large scale coverage holes with reasonable number of iterations even if all nodes participate in recovery process.

The paper is organized as follows: in Section II related work are presented. In Section III, the methods and assumptions are introduced. In Section IV, the results are demonstrated, and finally the paper is concluded in Sections V conclusion.

II. RELATED WORK

In order improve the coverage and nodes formation, among the solutions, relocation of currently deployed nodes offers a promising solution to emerging issues and challenges in wireless sensor networks. By harnessing the controllable and constrained node mobility a wide variety of relocation algorithms have been introduced in the literature [20]–[32] to
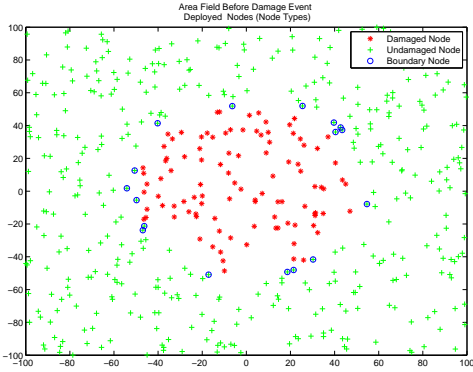
Fig. 1: Network Hole and Node Types

deal with unbalanced deployment and newly formed coverage holes, and to dynamically response to unpredictable topological changes in wireless sensor networks. By the advantage of WSNs' intrinsic redundancy, distributed relocation algorithms seems to be proper candidates for applications with lack of centralized control and supervision with harsh environments. In such environments, autonomous nodes should be able use their neighbours' status in order to make decision and interact locally among themselves and react swiftly in time sensitive scenarios to the changing environmental conditions.

Paper [29] classified relocation algorithms, apart from their span of design overlap and similarity into *virtual force-based* (radial [22], [33] or angular [26]), *voronoi-based* [27] and *flip-based* [21] movement algorithms. Regardless of the classification, each of the relocation algorithms is devised to reach performance goals (i.e. connectivity [26], lifetime [25], deployed node re-alignment [22], [29]–[32], small and large scale coverage holes recovery [21], [27], [29], virtual coverage hole displacement [34], etc.). However, whether these relocation algorithms have agreeable performance for other objectives than their primary design goals should be investigated in further details.

Although DSSA has a good performance with regard to amount of node movements and coverage [22] when it is applied to balance and align the node formations, it is shown in this paper that DSSA is not able to properly recover large scale coverage holes with the sufficient number of iterations even if all nodes participate in the recovery processes. In another scenario which DSSA only is applied to limited or select a set of nodes close (proximate)to the coverage hole (e.g. CH *boundary nodes*) [29], [35], [36] to limit node movements and power consumptions, DSSA ability of recovery worsen.

III. METHODS AND ASSUMPTIONS

In our scenario, homogeneous sensor nodes based on model of the unit disk graph (UDG) [37] randomly deployed with uniform distribution in a rectangular area of $[x_{min}, x_{max}] \times [y_{min}, y_{max}]$. For sake of simplicity, nodes' transmission ranges (R_c) and sensing ranges (R_s) are equal. Nodes are bidirectionally connected if they are within each other's ranges. Locations of sensors may be known by GPS or any other localisation methods [38]. Similar to [29], [35], [36],

sensor nodes are classified into into *damaged* nodes if they reside inside the *damaged area* (coverage hole); otherwise, they are considered as *undamaged* nodes. Those undamaged nodes proximate to the coverage hole which directly detect the *damage event* within their ranges are further defined as *boundary nodes* (Fig. 1). Coverage hole event is detected by boundary nodes as boundary nodes sense any significant changes within their ranges. (i.e. signal loss or disconnection as the result of the failure of their neighbours)

Similar to [29], [35], [36], coverage hole is modelled as a circle of radius r_{Hole} with the centre at x_{Hole}, y_{Hole} (Fig. 1). In this paper, *Distributed Self-Spreading Algorithm (DSSA)* [22], as one of force-based relocation algorithms with the promising performance in movement, uniformity and coverage, is applied to both boundary nodes and undamaged nodes in the network and their performances in term of coverage and the ability to repair damaged area is depicted in Figs. 2, 3. Similar to [30]–[32], nodes stop at the boundaries if their new locations obtained by relocation algorithm exceed the boundaries of the given area ($[x_{min}, x_{max}] \times [y_{min}, y_{max}]$).

IV. RESULTS

The model is simulated in Matlab and N=500 nodes with transmission and sensing range of R_c=R_s=15 deployed in the rectangular 2-D area of $[-100, 100] \times [-100, 100]m^2$. By considering boundary condition used in [30]–[32], DSSA applied to boundary nodes and undamaged nodes in the given area. Figs. 2, 3 show network deployment and coverage status before and after occurrence/recovery of coverage hole as DSSA algorithm performed on boundary and undamaged nodes in iteration $i = 50$. It should be noted that the most recovery is resulted form first 10 iterations. As the number of iterations increases the DSSA performance does not improve accordingly. Therefore according to Figs. 2, 3, although DSSA is an efficient relocation algorithm for aligning unbalanced deployments or repairing of small coverage holes, it is a not proper choice for recovering the large scale coverage holes.

V. CONCLUSION AND FUTURE WORK

In this paper as one of force-based relocation algorithms, DSSA is chosen for recovery of large coverage hole. DSSA recovery capability and efficiency in term of coverage has been demonstrated as it is applied to both boundary and undamaged nodes. It is shown that DSSA is not proper choice for recovery of large scale coverage hole even if all network's nodes participate in the recovery process and/or the number of relocation iterations are increased sufficiently. As the possible future work, clear definition of small and large scale coverage holes can be presented. Recovery capability and efficiency of other conventional relocation algorithms in the case of small/large coverage hole can be investigated and their results can compared quantitatively in terms of different performance metrics.
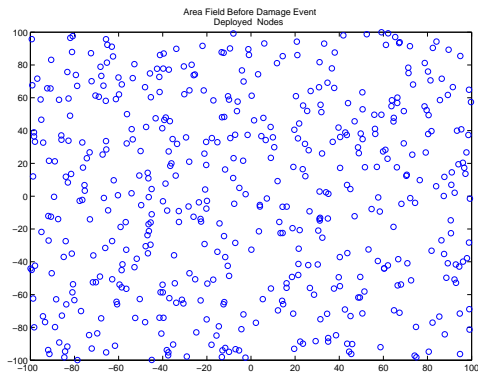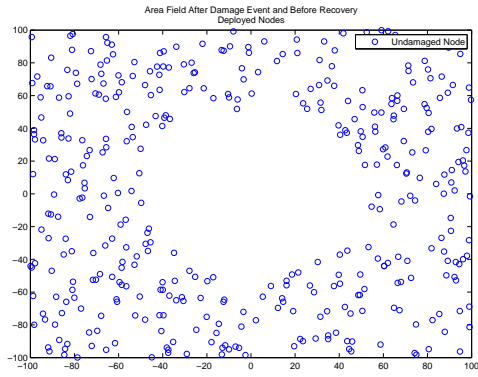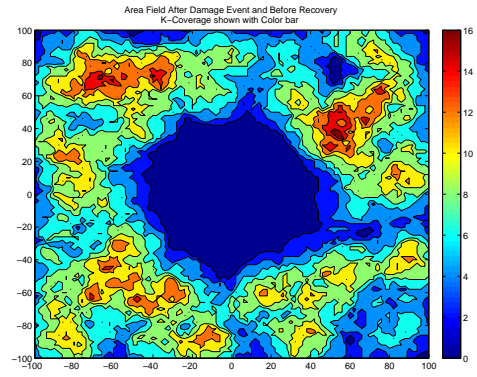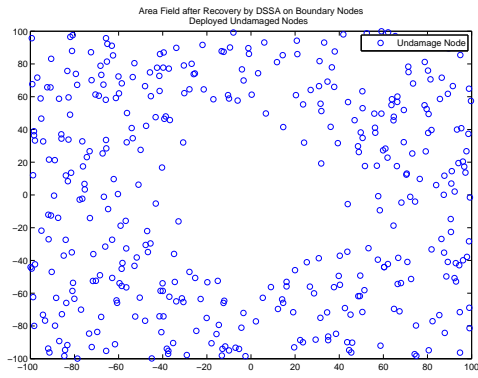
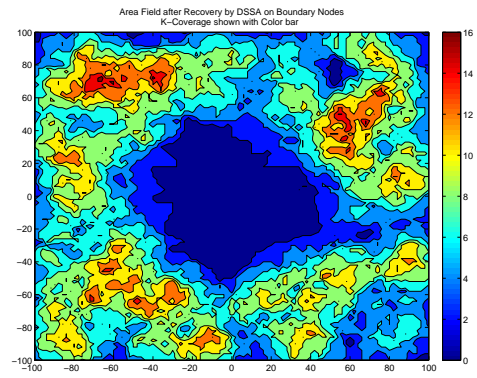(a) Initial Network Deployment
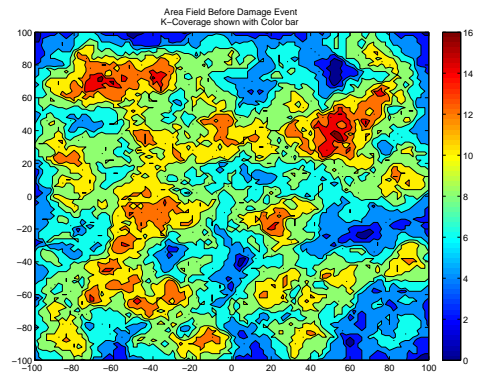
(a) Initial Network Coverage

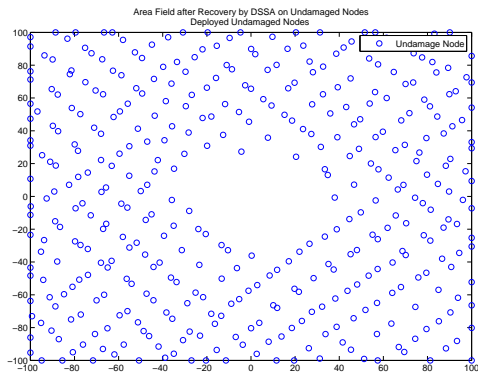(b) Network Deployment After Coverage Hole/Before Recovery

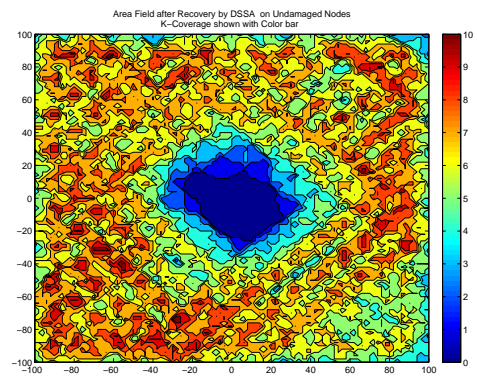(b) Network Coverage After Coverage Hole/Before Recovery

(c) Network Deployment After Recovery using Boundary Nodes

(c) Network Coverage After Recovery using Boundary Nodes

(d) Network Deployment After Recovery using Undamaged Nodes

(d) Network Coverage After Recovery using Undamaged Nodes

Fig. 2: Network Deployment Stages in the Recovery, Performed by DSSA on Boundary/Undamaged Nodes

Fig. 3: Network Coverage Stages in the Recovery, Performed by DSSA on Boundary/Undamaged Nodes

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Performance Testing of CoMP Handover Algorithms in LTE-Advanced

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Abstract—**Coordinated Multiple (CoMP) Transmission and Reception technology is expected to enhance the Long Term Evolution – Advanced (LTE-A) system throughput and reduce the packet loss ratio (PLR) compared to the LTE system. However, this could lead to system capacity overload and saturated system throughput issues within a highly congested network. To address this situation, this paper describes three proposed CoMP handover algorithms for the LTE-A system. These algorithms take one or more decision criteria into consideration to increase system capacity. System performance of each proposed CoMP handover algorithm is evaluated and compared with open literature via computer simulation. Simulation results are provided with a handover parameters optimization and a discussion of the performance testing.**

Keywords-3GPP LTE-Advanced; Handover Algorithm; CoMP Transmission/Reception; Joint Processing;

I. INTRODUCTION

One of the major attractions of mobile communication is service continuity for mobile users. Handover (HO) plays a fundamental role while balancing traffic load and supporting service continuity. HO can be categorized as hard HO and soft HO. Hard HO is commonly used when dealing with handovers in the legacy wireless systems as well as in the Long Term Evolution-Advanced (LTE-A) system [1]. The hard HO is a category of HO procedures where all the old radio links in the user equipment (UE) are abandoned before the new radio links are established. Coordinated multipoint (CoMP) transmission and reception technology is a key technique in LTE-A to improve the cell-edge data rate and average data rate, and is suitable to increase the spectral efficiency (and hence the capacity).

Two types of CoMP schemes were evaluated for LTE-A system: Joint Processing (JP) and Coordinated Scheduling / Beamforming (CS/CB). JP provides multiple data transmissions for each UE among multiple cooperated eNodeBs while CS/CB supports single data transmission for each UE at serving eNodeB with user scheduling/beamforming decisions

made with coordination among cooperated eNodeBs [2]. Fig. 1 shows an example of CoMP with CS/CB and JP transmission in a distributed network architecture.
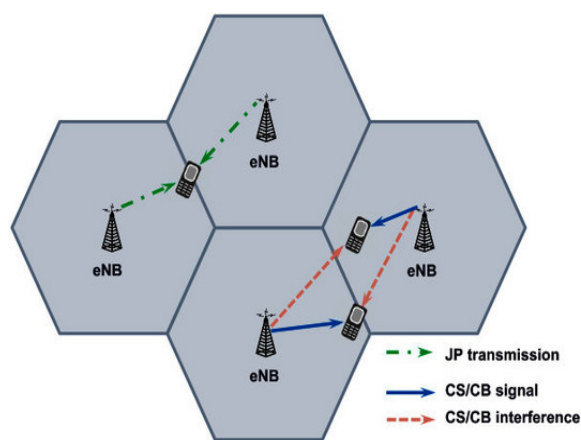

Fig. 1: Example of CoMP in a distributed network architecture System [3]

A HO algorithm is needed for making a HO decision. Due to the characteristic of multiple data transmissions JP provides, a new HO algorithm supporting JP in LTE-A system is essential. Handover Mechanism in CoMP [4] is able to improve the system throughput performance by allowing multiple transmissions for each UE at any time. However this mechanism could lead to a system capacity overload and high system delay due to multiple resources each UE required among multiple eNodeBs. Hence a new HO algorithm supports CoMP and takes system capacity into consideration in LTE-A system is necessary.

In this paper, three proposed CoMP HO algorithms are introduced. The parameters of each CoMP HO algorithm are optimized followed by a simulation of performance testing of three poposed CoMP HO algorithms and open literature with mixed real-time (RT) and non real-time (NRT) traffic.

The rest of this paper is organized as follows: three proposed CoMP HO algorithms in LTE-A system are discussed in Section II followed by discussions on the simulation environment, traffic model, performance

metrics, and optimization in Section III. Section IV contains optimized performance testing with mixed RT and NRT traffic followed by the conclusion in Section V.

II. CoMP Handover Algorithms in LTE-Advanced

Three proposed CoMP HO algorithms in the LTE-A system are discussed in this section.

I. Limited CoMP Handover Algorithm [5]

Limited CoMP Handover Algorithm involves four concepts: serving cell, measurement set, CoMP coordinating set (CCS), and CoMP transmission points (CTP). A serving cell is the cell which takes the responsibility of making HO decision and maintains the connection of each UE to the network. An UE can only attach to one serving cell at each time instant. A measurement set is a set of cells whose reference signal received power (RSRP) can be received and reported by the UE to the serving cell. A CCS is a set of cells which are selected by the serving cell from the measurement set. Furthermore, A CTP is a set of cells chosen from the CCS by the serving cell for sending downlink data directly to an UE.

Three HO parameters are involved in the Limited CoMP Handover Algorithm: measurement period, HO margin (HOM), and time to trigger (TTT) timer. A measurement period acts a time period that is used for checking the handover condition periodically. A HOM is a parameter that represents the threshold for the difference in RSRP between the serving and the target cell. A TTT value is the time interval that is required for satisfying the HOM condition.

The Limited CoMP Handover Algorithm starts when the UE joins the network by camping on the cell whose RSRP is the highest or the cell which was instructed by previous serving cell. Then UE starts to feedback the serving cell with the measurement set which is the RSRP measurements received from all cells in the network. Serving cell selects a set of cells with highest RSRP in the measurement set as a CCS. The CTP selection will be recursively executed by serving cell until reaching the end of CCS based on the follows:

$$RSRP_{T\_CCS} < RSRP_S - HOM \qquad (1)$$

where $RSRP_{T\_CCS}$ and $RSRP_S$ are the RSRP received by an UE from the target cell in the CCS and the serving cell, respectively.

The target cell in the CCS will be ignored if Equation (1) is satisfied, otherwise the target cell in the CCS will be added into CTP. After CTP selection is finalized, serving cell performs HO condition check in CTP based on the Equation (2) expressed as follows:

$$RSRP_{T\_CTP} > RSRP_S + HOM \qquad (2)$$

where $RSRP_{T\_CTP}$ and $RSRP_S$ are the RSRP received by an UE from the target cell in the CTP and the serving cell, respectively. A flowchart of the Limited CoMP Handover Algorithm is given in [5].

II. Capacity Based CoMP Handover Algorithm [6]

A resource block (RB) utilization value is used in the Capacity Based CoMP Handover Algorithm and it evaluates the proportion of total used RBs to total RBs in each cell and describes the current state of the cell's capacity. It can be expressed as:

$$RButilization_c = RBused_c(t) / RBmax_c(t) \qquad (3)$$

where $RBused_c(t)$ denotes the total resource block been used of cell c at time t and $RBmax_c(t)$ denotes the total resource of cell c at time t. A higher RB utilization value indicates the cell becomes a saturated state, therefore a cell reselection needs to be considered when more UEs are going to be handed over to this cell. On the other hand, when the cell is having a lower RB utilization value, this cell is capable for accommodating more incoming UEs.

In the Capacity Based CoMP Handover Algorithm, the serving cell selects a set of cells with the lowest RB utilization value from the measurement set as CCS. The serving cell performs the CTP selection based on selecting a set of cells with the highest RSRP from CCS. A HO will be triggered when the Equation (2) is satisfied during the entire TTT duration, otherwise CTP starts transmitting data to the UE and waits for the next measurement period expires.

III. Capacity Integrated CoMP Handover Algorithm [7]

A historical RB utilization value is introduced in Capacity Integrated CoMP Handover Algorithm and it can be mathematically expressed as:

$$HisRButilize_c(t) = \frac{\sum_{t=1}^{t} RButilize_c(t)}{t} \qquad (4)$$

where t is the current time instant, $RButilize_c(t)$ denotes the RB utilize value of cell c at time t obtained from Equation (3). $HisRButilize_c(t)$ is the historical RB utilize value of cell c from time 1 until time t.

A new HO parameter is introduced known as the capacity indicator in the Capacity Integrated CoMP Handover Algorithm. Capacity indicator represents the proportional combination of historical RB utilize value and RB utilize value in current time instant and it can be further expressed as:

$$Capacity_c(t) = (1-\gamma)*HisRButilize_c(t-1) + \gamma*RButilize_c(t) \qquad (5)$$

where $HisRButilize_c(t-1)$ and $RButilize_c(t)$ is the historical RB utilize value and RB utilize value of cell c at current and previous time instants, respectively. γ is a constant factor between 0 and 1. The closer the γ equals to 1, the capacity indicator will be based on

more portion of the RB utilize value at the current time instant. On the other hand, the closer the γ reaches 0, the capacity indicator will be based on more portion of the historical RB utilize value at the previous time instant. A capacity indicator represents the current state of the cell's capacity and takes the cell's historical measurement into concern. A cell's capacity condition is expressed as following:

$$Capacity_c(t) \leq Capacity\ Threshold \qquad (6)$$

where $Capacity_C(t)$ is the capacity indicator of cell c at time t. Capacity Threshold is a decimal constant factor between 0 and 1. A capacity threshold value is used for determining appropriate target cells whose current and historical capacities are able to accommodate the incoming UE.

In the Capacity Integrated CoMP Handover Algorithm, the target cells within the measurement set which satisfy the Equation (6) will be recursively selected as CCS by the serving cell. Moreover, the CTP selection will be recursive based on selecting a cell with the highest RSRP from CCS. A HO will be triggered when the triggering condition (2) is satisfied fulfilled the entire TTT duration; otherwise the CTP transmits data to the UE and waits for the next measurement period expires. A flowchart of the Capacity Integrated CoMP Handover Algorithm is given in [7].

III. SIMULATION ENVIRONMENTS AND PERFORMANCE METRICS

The performance of three proposed CoMP handover algorithms and the open literature is evaluated using a computer simulation. The system parameters used in the simulation are listed in Table I.

TABLE I.   3GPP LTE-A SYSTEM PARAMETERS

Parameters	Values
Cellular layout	Hexagonal grid, wrap around (reflect), 7 cells
Radius	100 m
Carrier Frequency	2 GHz
Bandwidth	5 MHz
Number of RBs	25
Number of sub-carriers / RB	12
Sub-carrier Spacing	15 kHz
Slot Duration	0.5 ms
Number of OFDM Symbols / Slot	7
Path Loss	Cost 231 Hata model [8]
Shadow fading	Gaussian distribution [9]
Multi-path	Rayleigh fading [10]
Modulation and Coding Scheme	QPSK, 16QAM, and 64QAM
HARQ / Retransmission	Enable / 3 times [11]
Packet Schedule Algorithm	Proportional Fair

Parameters	Values
Handover Algorithm (HOA)	5: CoMP Handover Algorithm [4] 6: Limited CoMP Handover Algorithm 7: Capacity Based CoMP Handover Algorithm 8: Capacity Integrated CoMP Handover Algorithm
Data Traffic	NRT Traffic: Web browsing D_{pc}= 30 ms [12] RT Traffic: 1 Mbps Constant Stream
NRT / RT traffic	75 users
User's position	Uniform distributed
User's direction	Randomly choose from [0,2π], constantly at all time
User's velocity	3, 30, 120 km/hr
Simulation time	10000 ms
Scheduling Time (TTI)	1 ms
Measurement interval	10 ms
Size of CCS and CTP	3 and 2
γ / Capacity Threshold	0.75 / 0.9

The parameters for each CoMP handover algorithm are optimized using the approach in [13]. The optimized parameters of all CoMP handover algorithms under three speed scenarios are summarized in Table II.

TABLE II.   OPTIMIZED PARAMETERS OF CoMP HANDOVER ALGORITHMS

km/hr	HOA 5	HOA 6	HOA 7	HOA 8
3	[HOM, TTT] = [4, 5]	[HOM,TTT] = [4, 4]	[HOM, TTT] = [5, 3]	[HOM, TTT] = [4, 3]
30	[HOM, TTT] = [4, 5]	[HOM,TTT] = [5, 4]	[HOM, TTT] = [4, 1]	[HOM, TTT] = [5, 1]
120	[HOM, TTT] = [5, 4]	[HOM,TTT] = [5, 3]	[HOM, TTT] = [5, 5]	[HOM, TTT] = [5, 0]

The performance testing of four CoMP handover algorithms are on the basis of system throughput.

System throughput is defined as the total number of bits correctly received by all users and can be mathematically expressed as:

$$system\ throughput = \frac{1}{T}\sum_{t=1}^{T}\sum_{i=1}^{I} ptransmit_{c\_i}(t) \quad c \forall CTP_i \quad (7)$$

where I is the total number of UEs, T represents the total simulation time, and $ptransmit_{c\_i}(t)$ denotes the number of transmitted bits of cell c whichever earlier received by UE i at time t. Cell c belongs to CTP of UE i.

IV. SIMULATION RESULTS

Fig. 2 shows the system throughput of four CoMP handover algorithms with mixed RT and NRT traffic under three different user's speeds in LTE-A simulation. HOA6 offers the highest system throughputs of 106.374 Mbps and 91.4014 Mbps at 3 and 30 km/hr scenarios, respectively. HOA6 offers the second highest system throughput of 63.641 Mbps at 120 km/hr scenario. HOA6 performs a lower system throughput at 120 km/hr scenario is because the mechanism in HOA6 constantly checks the RSRP of the target cells in CCS which increases the feedback messages and signaling overhead from UEs at any time instant, therefore the system throughput is affected and decreased in 120 km/hr scenario.
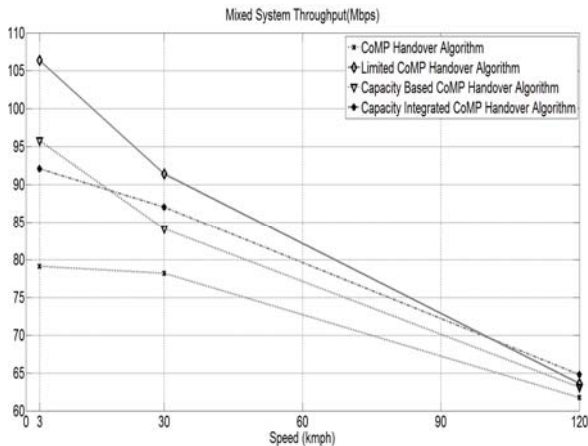

Fig. 2: System Throughput of Four CoMP Handover Algorithms for Mixed RT and NRT Traffic in LTE-A

HOA7 and HOA8 offer the second highest and the third highest system throughputs of 95.8426 Mbps and 92.1148 Mbps at 3 km/hr scenario. HOA8 outperforms HOA7 in the scenarios of 30 km/hr and 120 km/hr due to the assistance of the Capacity Threshold factor which restricts the cells in the measurement set become the target cells in the CCS of each UE. Therefore the available radio resources in the target cells in the CCS can be further utilized by other UEs, thus the system throughput is enhanced.

HOA5 has the lowest system throughput of 79.1266 Mbps, 78.2245 Mbps, and 61.7326 Mbps at 3 km/hr, 30 km/hr, and 120 km/hr scenarios, respectively. HOA5 fully uses the multiple transmission points of each user in the system which makes each eNB saturated in the system and results the lowest system throughput in every speed scenario.

V. CONCLUSIONS

Three proposed CoMP handover algorithms for LTE-A system are introduced in this paper. Performance testing of each CoMP handover algorithm is evaluated and compared to the open literature via simulation. It is shown via simulation that the Capacity Integrated CoMP Handover Algorithm provides the highest system throughput with Mixed RT and NRT traffic at 120 km/hr. The performance testing of four CoMP handover algorithms with individual RT and/or NRT traffic will be the focus of the future studies.

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Modelling and Simulation of Wi-Fi Positioning System Deployment for Pedestrian Monitoring

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Abstract— **Wi-Fi Positioning System (WPS) is a localization technology based on WLAN infrastructure and used the signal strength to implement position determination. With the widely used of Wi-Fi integrated smartphone, WPS has been introduced to monitor pedestrian movement such as movement trend and pedestrian traffic load. The information of pedestrian in a street can be used to improve the services provides to people, for instance, a better bus time schedule and more friendly pavement design. Although there are lots of paper relate to WPS, but very little works has been published to discuss the system deployment. This paper provides modelling and simulation of WPS deployment in a street environment using MATLAB simulation tool. The results of the simulation can be used to optimizing WPS device deployment to achieve better system coverage and efficiency.**

Keywords——**WPS, Deployment, Modelling, Simulation**

I. INTRODUCTION

Wi-Fi Positioning System (WPS) have drawn the attention of research community in the past few years. It relies on WLAN infrastructure to provide low-cost location service. WPS sniff the packets transmitted by Wi-Fi devices and extract the information of captured packets such as signal strength and captured time. The sniffing device needed for WPS can easy obtain from market: router and Wi-Fi adapter, for instance.

Mobile tracking system is one application of WPS, which is used to monitor the pedestrian movement and density in a street. To detect the available network, the Wi-Fi enabled smartphone which is carried by most of pedestrian traffic points scans the Wi-Fi band intermittently. The typical packet involves in this detecting processing is probe request. Each packet contains a unique device number (MAC address). By deploying the mobile tracking system in an area of interest, the packet which sends by the passed through smartphone can be captured [1]. It is possible, to estimate the location of a smartphone as well as the holding person by using the information of the captured packet such as the MAC address and received signal strength [2, 3].

The mobile tracking system is dividing into two building blocks: sniffing block and administration block.
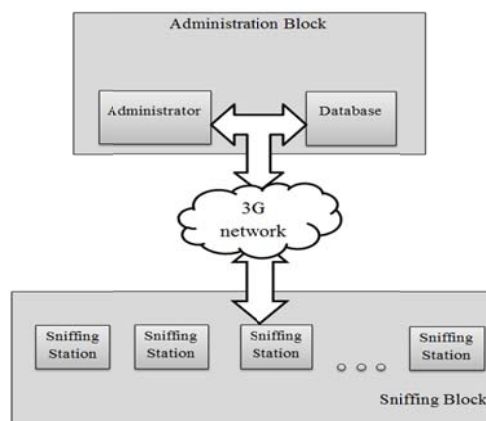

Figure 1: The building block of mobile tracking system

The Figure 1 demonstrates the structure of the building blocks. In the sniffing block, it contains several sniffing stations which are used to capture the Wi-Fi packets. The sniffing station consists of microprocessor, memory, Wi-Fi adapters, antennas and 3G modules. The sniffing station extracts packets related information: hashed MAC address, received signal strength indication (RSSI), captured time and sniffing station ID. Then, the information is written into a file and sends to administration block. In administration block, a database is used for data storage and back up. An administrator can access to the sniffing station remotely via 3G network and obtain the collected data from the database.

Although it is not a new topic to track vehicles and individuals by using WPS, however there is very little work has been published for the system deployment. This paper provides modelling and simulation for WPS deployment in a street environment.

The remainder of this paper is structured as follows. Section 2 describes the system model for mobile tracking. By following, the simulation module is discussed in Section 3.Section 4 contains the simulation environment and results. This paper is concluded in Section 5.

II. MOBLIE TRACKING SYSTEM MODEL

In mobile tracking system, the sniffing station passive listens the Wi-Fi channel and captured the transmitted packets. But, Wi-Fi technology has 14 channels, therefore, in order to

scan all the channels the sniffing station has to apply channel hopping.

In this paper, it is assumed that the street does not have Wi-Fi network and the Wi-Fi enable smartphone broadcast the probe request only. In broadcast procedure, the smartphone sends probe request on one channel and wait at least "MinChannelTime" [4] for response then hop to another channel until all the channels have been scanned. The Figure 2 describes the flowchart of mobile tracking system model.
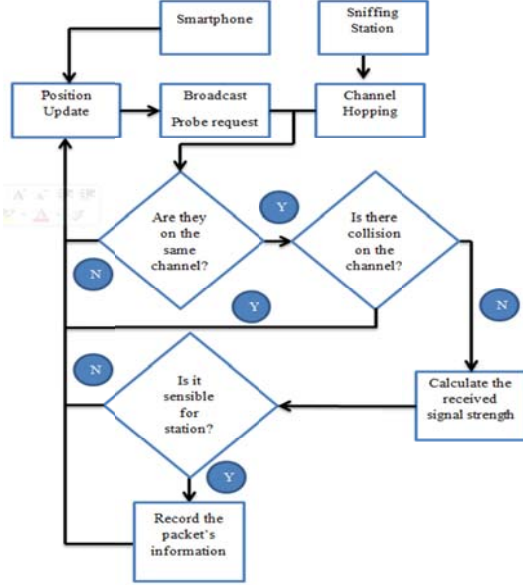

Figure 2: The mobile tracking system model

III. SIMULATION MODEL

A MATLAB simulation tool was developed to model and simulate the sniffing station operation, pedestrian movement and smartphone behaviors. The tool consists of four modules: mobility module, packet generation module, radio propagation module and channel hopping module.

A. Mobility Module

This module simulates the pedestrian traffic in a street crossing which is shown in Figure 3 and the blue block in the figure is the buildings beside the street. The basic unit for pedestrian traffic is a group and all the individual people within a group have same moving speed and direction. The group can enter or exit this area from 8 ports (A - H) distributed randomly. Some parameters in this module are used to describe the pedestrian traffic: group size, group velocity, traffic load, group reference position and group vector.
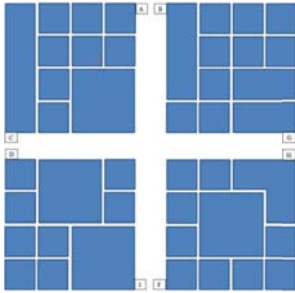

Figure 3: The simulated street crossing

The group size gives the number of members in a group. In a street, most pedestrian group contains 1 and 2 people [5, 6]. Therefore, in the simulation, the group size for each group is randomly chosen from 1 to 5 with normal distribution which mean is 2 and standard deviation is 3.

The group velocity presents the pedestrian group walking speed. The Table 1 summarized pedestrian walking speed study in different countries. Based on this study result, the group velocity for each group is randomly chosen with normal distribution which mean is 1.33 and standard deviation is 0.42.

TABLE I. The pedestrian walking speed [7]

Country	Mean(m/s)	Standard deviation
Netherland	1.14	0.22
United State	1.4	0.15
Australia	1.44	0.23
Hong Kong	1.19	0.26
United Kingdom	1.32	1.00
India	1.46	0.63
Average	1.33	0.42

The traffic load is the frequency for a new pedestrian group enters the street crossing. This parameter is used to simulate different pedestrian traffic load in a day such as the peek-time and peek-off time.

The group reference position is used to mark a group location. The new location for group i ($loc_i(t+1)$) is determined by using the equation:

$$loc_i(t+1)) = loc_i(t)+(v_i \times dir_i) \qquad (1)$$

where v_i is the group velocity and dir_i is the moving direction which is a fixed angle (0°, 90°, 180° and 270°) depends on the entry port. The moving direction can change 0°, +90° or -90° randomly when the group meets the street turning.

The group vector (vec_j) is used to determine the position for each group member ($position_j$). The position for member j in group i can be determined by using the equation:

$$position_j(t) = loc_i(t) \times vec_j \qquad (2)$$

This mobility module is a pass-through method which means the pedestrian group not stays in the simulation area when it reaches the exit port. The tool not updates the information for the left group any more.

B. Packet generation module

This module generates probe request for the smartphone in each group. As the probe request is very small packet and is transmitted with a fixed data rate 1Mbps. Therefore, this module only considers the packet generates frequency.

A Wi-Fi enabled smartphone has two operation modes: standby mode and active mode. Under active mode, the smartphone is fully running and sends probe request frequent. On other hand, the smartphone sleeps for power saving, when under standby mode. This paper studied 4 major brand smartphones in the markets and the result is presented in Table 2.

TABLE II. Probe request sending frequency

Brand	Operation System	Mode	Average value(packets/min)	Standard Deviation
HTC	Android v2.3	Standby	0.86	0.11
		Active	3.53	0.12
Samsung	Android v4.2.1	Standby	0.60	0.40
		Active	0.73	0.64
Apple	IOS 6.1	Standby	0.07	0.12
		Active	1.13	1.62
Sony	Android v4.1.2	Standby	0	0
		Active	3.73	0.70

By following this table, the simulation tool provides 4 kinds packets sending frequency and randomly allocate to the members in pedestrian group. The allocated packets sending frequency randomly switch between standby mode and active mode by following the mechanism which is shown in Table 3.
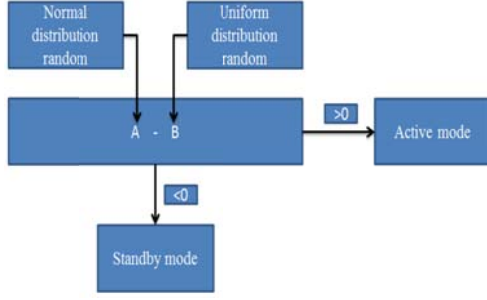

Figure 4: Standby mode and active mode selection

The mean of normal distribution random is 0, standard deviation is 3 and the mean of uniform distribution random is 2.2 and standard deviation is 0.5. This method can simulate the smartphone state in a street, which is under standby model in most of time.

C. Radio propagation Module

The received signal strength is needed to determine the capture the radio signal is sensible for sniffing station. The radio propagation module uses group velocity and position for each pedestrian group in order to computer the path-loss, shadow and multi-path gain. The log-distance model [8] is used to calculate the path-loss and consists of the following equation:

$$PL(dB)=PL(d_0)+10nlog(d/d_0) \qquad (3)$$

where PL is the path-loss, d_0 is the reference distance which usually is 1m, d is the distance between the smartphone and sniffing station and n is the path loss exponent.

By considering the shadowing effect, the Eq.3 becomes to:

$$PL(dB)=PL(d_0)+10nlog(d/d_0)+X_{dB} \qquad (4)$$

where X_{dB} is a Gaussian distributed random variable with 0 mean. In terms of X_{dB}, it models the path loss variation across all locations from the smartphone due to shadowing.

The path loss exponent in Eq.4 describes the environment condition effect. In the simulation, the n randomly choose from 2.7 to 3.5 when there is line-of-sight between smartphone and sniffing station or randomly choose 3.5 to 5 when the smartphone is blocked by buildings [9].

A simulator developed by Komniakis [10] which using Rayleigh distribution to generate multi-path gain. The multi-path gain is related to the pedestrian walking speed and Wi-Fi carrier frequency.

Therefore, in this paper, the received signal strength for smartphone hold by group member j (RSS_j) consists of the following equation:

$$RSS_j(dB)=Tx_j(dB)- PL_j(dB)-mpath_j(dB) \qquad (5)$$

where $Tx_j(dB)$ is the transmitting power for smartphone and $mpath_j(dB)$ is the multi-path gain.

D. Channel hopping module

This module is used to simulate the channel hopping which is occurred in sniffing station. The hopping time (Th) is the time sniffing station spent to scan one channel. The sniffing station supports three hopping methods which are First-In First-Out (FIFO), Round Robin (RR) and Hop On Last (HOL).
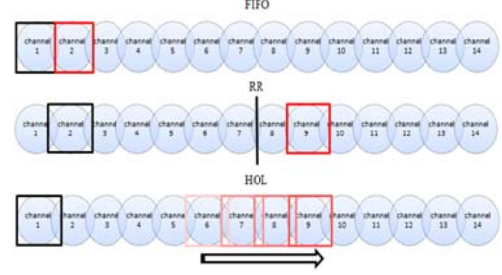

Figure 5: The channel hopping method

The Figure 4 demonstrates the details of the three methods. Specifically, in FIFO method, all the monitoring devices hop simultaneously and following each other. In RR method, every monitoring devise have own hopping section, they scan their own section only. In HOL method, the last monitoring devices hop on the channels and others is fixed to scan one channel only.

IV. SIMULATION RESULT ANALYSIS

A. Signal station simulation

The simulation deployment area is the street intersection and the all of the simulation parameters are shown in Table III.

Table III: The mobile tracking system simulation parameters of single station simulation scenario

Parameter	Value
Sniffing station sensitivity	-93dbm
Number of monitoring devices	2
Traffic load	Fixed number of pedestrian
Street length	100m
Street width	30m
Max_channel_Time	1ms
Hopping method	HOL
Selected channels	1, 6, 11
Simulation time	600000ms

In the simulation, the factors which can affect packet sniffing are received signal strength and packet generation rate. However, only the signal strength is directly related to the position of the sniffing station.
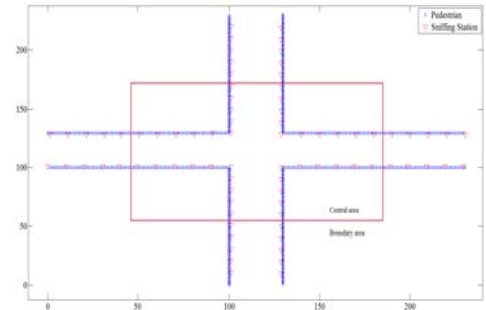

Figure 6: The pedestrian and sniffing stations distribution of the first scenario

The 800 pedestrians are evenly distributed and their positions are fixed in this simulation scenario. As shown in Figure 6, the simulation area is divided into two parts: central area and boundary area. In the figure, the circle marks represent the positions of pedestrians and pedestrians send packets once. The triangle marks represent the location of sniffing station and 80 locations have been used in the simulation.

The simulation result is shown in Figure 7 and it can be observed that the sniffing stations captured more packets from the central area than the boundary area. The main reason is that the sniffing stations located at central area and shorter distance to the pedestrians in both horizontal and vertical direction. Specifically, the sniffing station which located at the four highest positions in the Figure 7 has line-of-sight to all pedestrians.
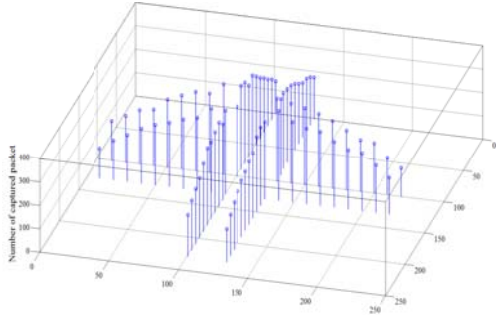

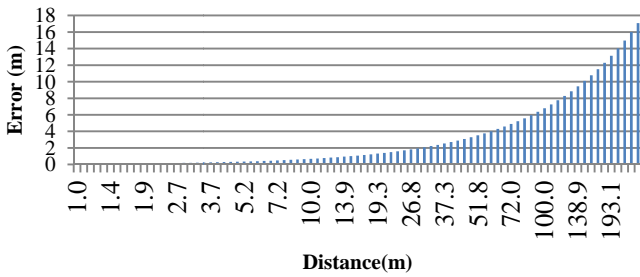Figure 7: The result of first simulation scenario

Figure 8: The localization error at different distance

However, it is hard to achieve optimal localization if all the sniffing stations are deployed within a central area, as the basic requirement of triangulation is that the sniffing stations must well-spaced. Therefore, some sniffing stations have deployed at the boundary area. A simulation was conducted to study the localization accuracy at different distances between sniffing stations and pedestrians. Based on the simulation result which is shown in Figure 8, the localization error for mobile tracking system can be classified into some categories which a shown in Table IV. The option of accurate and good category is more costly as they need more sniffing stations to cover an investigation area. Therefore, the normal and acceptable option is suggested for balance the system cost and localization accuracy.

Table IV: The localization error category

Category	Error (m)	Distance(m)
Accurate	<1	<14
Good	1~3	<42
Normal	3~5	<72
Acceptable	5~8	<114

V. CONCLUSION

In this paper a simulation tool which was developed based on MATLAB has been introduced. This tool comprises four major models, the mobility model is used to simulate the free-walking pedestrian movement; the packets generation model is used to simulate the probe request broadcasting. The generation rate for the probe request is based on the field test results. Radio propagation model is used to calculate the received signal strength and the channel hopping model is used to simulate the channel scanning, packets capturing and channel hopping function of the sniffing station. In addition, this simulation tool is validated with field test and obtained the similar result.

After conducting the three simulation scenarios of sniffing station deployment, the investigated area (simulation area) is divided into central area and boundary area and the deployment suggestion is given as: a) more sniffing stations are needed to deploy in central area. b) at each direction of the street intersection, at least one sniffing station is needed to deploy in the boundary area.

VI. REFERENCE

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