Performance Evaluation of Relay Deployment in Long Term Evolution Advanced (LTE-A) Network

Aminah Najihah Binti Jaafar
Faculty of Electrical Engineering, Universiti Teknologi MARA (UiTM),
40450 Shah Alam, Selangor Darul Ehsan, Malaysia
aminah.najihah@gmail.com

Abstract — **Normally, the cell-edged users in wireless networks experiencing a low Signal-to-Interference-Noise-Ratio (SINR). This problem will result in low signal strength and it will cause a bad performance for the overall system. Moreover, the small cell capacity and cell coverage will occur at the cell-edge. To support a high data services and applications it is required a peak data rate. The enhancement of the cell-edge capacity as well as cell coverage are the expectation that can be provided by Long Term Evolution Advanced (LTE-A). In this paper, a new scheme for an optimum relay node (RN) placement in LTE-A cellular network to enhance the coverage extension at cell-edges region is proposed. It is due to user with low SINR will hand over to the relay node (RN) and will efficiently utilize the system resources. Various LTE-A technologies including RN deployments have been studied to meet these requirements. To provide high data rates coverage with a minimum operator cost is the advantage of RNs. Algorithms to determine the minimum distance between users and both BS and RN and the signal strength received in the proposed scheme also provided. The simulation results indicate an improvement in signal strength for the deployment of fixed relays.**

Keywords — Long Term Evolution Advanced (LTE-A), relay node, throughput, coverage, signal strength, cell-edge

I. Introduction

LTE Release 10 or better known as Long Term Evolution Advanced (LTE-A) offers better network performance than LTE Release 8 [1]. To propose more reasonable techniques that enable to produce higher data rate than before is the most important key for current and future mobile generations. To achieve this goal, there are a lot of techniques were proposed in LTE-A network in order to improve the performance [1], [2].

One of the effective solutions among several techniques is by introducing Relay Station (RS) or also known as Relay Node (RN) between Base Station (BS) and Users Equipment (UEs), as in Figure 1. The RS is connected to BS through a wireless link. This will help in reducing the cost of network deployment [3]. Enhancing both coverage and network capacity is the aims of LTE-A relaying. One of the primary drivers for the LTE-A users is to achieve the higher data rates. However all technologies suffer from the reduced data rates at the cell edges that caused a lower signal level and higher interference level. Due to inter-cell interference it resulted in the cell edge users having problems getting high Signal-to-Interference-plus-Noise-Ratio (SINR). This problem can be alleviated by applying relays [4]. Relay responsibilities are to receive, demodulate and decode the data and then apply any error correction. After that it will retransmit a new signal to UE. So the signal quality can be improved with LTE-A relay rather than suffering degradation from the reduced SINR when using a repeater [5].

Figure 1 : Schematic diagram of relay transmission [3].

There are two techniques of RSs named Amplify-and-Forward (AF) and Decode-and-Forward (DF). In AF RSs technique, the signal that received will be amplified before it forwarding a copy. The quality of the signal will be degraded since its signal is not decoded. AF relays are low complexity and easy to implement compared to DF relays due to the presence of the decoder and encoder in DF relays. In DF RSs technique it will decodes the received signal and then re-encodes it before transmitting a copy. The existence of all the noises in the received signal is cleaned out during the decoding process.

Transparent relays and non-transparent relays are the two types of DF relays. There are no communication of any control signals between transparent RSs and Mobile Station (MS). This is because the MS is unaware by the presence of these RSs. MS can receive control signal from non-transparent RSs. Most of the functions of established BS can be performed by non-transparent RSs. A MS handed over to RS when it is closest to RS and moves away from BS and the procedure the procedure is similar to an inter BS handover. To differentiate RS and the full-fledged BS is their connection to network since full-fledged BS is directly connected to the backhaul network. The MS will transmit enough power to reach the RSs in the uplink transmission because pilot signals are transmitted to the MS by non-transparent RS. This situation will result in a better network coverage and a significant power saving on the MS [6].

Relaying architectures can be classified into two, Fixed Relay Node (FRN) and Moving Relay Node (MRN). In 3GPP LTE-A FRN has been considered for their coverage extension. This situation continuous until Release 10 and for the next releases MRN might be considered. MRN provides services that are not accessible by fixed relays such as for passengers in a train, bus or riverboat. MRN can be divided into three sub categories. First one is dedicated moving relays serving stationary users. The probability of radio link failure of the users can be significantly decreased by using AF moving relays. Next one is dedicated moving relays serving non-stationary users. This type of MRN also placed on the transportation vehicles such as buses. However, it is providing coverage to the streets or in the parks rather than provide services to the passengers. The last one is user terminals as moving relays. This type of relay can be used by operators to provide relaying functionalities [7].

The reason why relaying technique was chosen as an enhancement to the current network is described in the literature review.

The rest of this paper is organized as follows. Section II elaborates several literature reviews from previous studies on relaying in communication network. Then, Section III presents the research methodology of this project. In Section IV, the results for measurement and simulation are shown and an analysis and brief discussion is included. Finally, conclusion and the future work recommendations are presented in Section V.

II. Literature Review

There are many studies that have been proposed on the evaluation for the performance of relay-based cellular network. The research in [8] proposed a fluid model with relays for cellular networks that create a simple formula that allow a fast analysis on the cell capacity and Signal-to-Interference-plus-Noise-Ratio (SINR) distribution. It shown that the overall signal quality in LTE-A network are decreases when relays are added. Furthermore, it is not appropriate to deploy relays on the upper bound of the radio resources proportion that is reserved to the backhaul link. It is caused by the obtained losses by the network is outperformed the defined gain.

From the studies in [9], Relay Site Planning (RSP) was proposed as an enhanced technique of wireless relay link for relay performance. This research was done by change their flexibility of deployment. Through the simulation it shows that RSP not increase the average of SINR but it also decreased the Amount of fading (AoF) on the link of the relay and it produced a low SINR particularly. Moreover, the maximum end-to-end gains that obtained being negligible when the bottleneck is performed as an access link.

According to [10], the capacity for cell-edge users increases by adding relay to the cell. It is due to their proposed of an optimization framework so that the total cell-edge or cell capacity can be optimized. More practical mathematical methods are needed to solve large scale problems because it needs a deep and complete research in this case. Other than that, it will be more realistic when a random user distribution is added into the system model so a random UE position will be generated.

The high quality links in mobile networks can be broken easily since it is impermanent. So the proposed scheme in [11] can help in making a bridge on the broken links besides maintain the topology robustness. Unfortunately the forwarder list is not sufficient anymore to regulate the sequence of data transmissions since more nodes in opportunistic data forwarding are involved. So the promising topic in the future works may include the action on how to depress the collisions and decrease the coordination overhead.

In [12], relay assisted Orthogonal Frequency Division Multiple Access (OFDMA) network deployment was proposed. It shown a big advantages by reducing the cost of BS and replaced it with fixed network. Since the future cellular networks unable to cover the radio range network as nowadays cellular network, so a relay deployment for the extension of radio range is necessary.

The authors in [13] have studied the problem of joint RN placement and sub-carrier allocation (RNP-SA). This research was done with renewable energy sources in two tiered wireless communication network. To find the minimal number of RNs to fulfil the users Quality of Service (QoS) demands under the energy sustainability and cost constraint, the two low complexity algorithms with RNP-SA was formulated as a mixed-integer non-linear programming (MINLP) problem. The proposed algorithms show a significantly outperform of a greedy algorithm by considering the constraints of energy and traffic. A dynamic energy charging can be considered as a new process to solve RNP-SA problem in future.

Based on these previous studies, it has been proven that the coverage of the BS especially in bad service areas or at the cell-edges have the high potential to be extended by deploy relays. So, in this paper a study on a simulation of the relay deployment in LTE-A network will be carried out to investigate the validity of this assumption.

III. Research Methodology

This project is divided into two parts, measurement and simulation. For the measurement part, drive test was done in a train by using RF Signal Tracker application from Padang Jawa, Shah Alam to KL Sentral, Kuala Lumpur. Drive test (DT) is a test performed in cellular networks regardless of technology such as in Global System for Mobile (GSM), Code Division Multiple Access (CDMA), Universal Mobile Telecommunications System (UMTS), LTE and others. It was used to collect data on the moving vehicles. By doing DT it can help in identify the signal strength, signal quality besides of determine the problem such as dropped calls. DT is fundamental for the work in the field of Telecom and

Information Technology (IT). Its analysis consists of two phases, which are data collection and data analysis. To collect the test data is the main purpose of doing the drive test. A view of the network performance on the field test are allowed since the data collected can be viewed or analyzed in a real time or live during the DT was taken [14].

There are various engineering applications of doing a DT. For this study, RF Signal Tracker was used since it is a free application and can be installed in Android phone. With this application, the Received Signal Strength Indicator (RSSI) and serving cell locations can be monitored, recorded and saved. The coverage zone of the cell sites also describe in this application. The stored data can be played back anytime whenever it is needed [15].

The RF Signal Tracker application can be downloaded from Play Store using the cellphone. It interface is as shown in Figure 2. From Figure 3, it shows the signal strength marker as the drive test was conducted from Padang Jawa to Kl Sentral that has been converted from KML file in this application to Google Earth. RF Signal Tracker application has selection of colours that will leave markers as user travel from one point to another point that indicates the signal strength at that area. The maker colour will indicate the signal strength at that point. The color selection are divided into 3 :

- Solid red (no signal) – about -113 dBm
- Yellow (moderate signal) – about -84 dBm
- Green (strong signal) – about -59 dBm

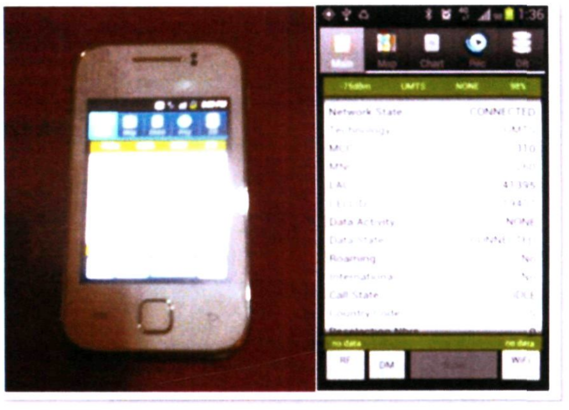

Figure 2 : The equipment of drive test and interface of RF Signal Tracker application.

Figure 3 : Signal strength marker between Padang Jawa- KL Sentral.

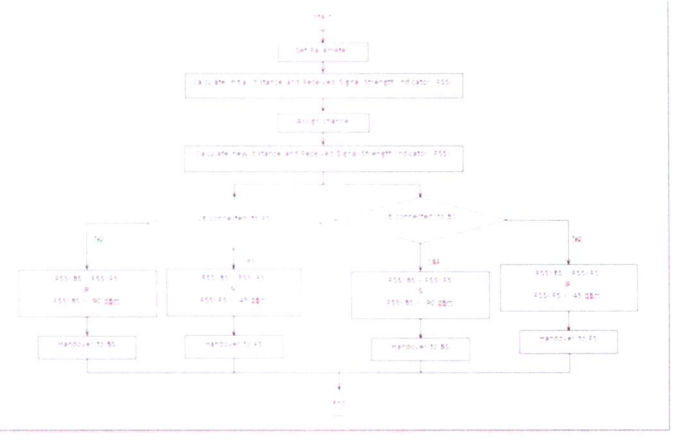

Figure 4 : The flowchart of handover for relay deployment.

Figure 4 shows the flowchart of handover for proposed relay deployment in LTE-A for simulation part. In this study, a network of seven cells per cluster is considered. Similar to other cellular networks, the location of the BS is at the centre of each hexagonal cell. The architecture of the cells can be seen as in Figure 4. The RSs placement are categorized into three types, random RSs, six fixed relays per cell and three fixed relays per cell.

Six fixed relays and three fixed relays are placed in each cell as new network elements that help in enhancing the cellular performance. The distance between each relay and the BS is 2/3 from cell radius as in Figure 7 and 8 [16].

Initially UEs are located at the North-East part of the cells architecture and it will move with the speed 110 km/h toward South-West. Firstly, the distance and RSSI were measured for both UE-RS and UE-BS. The distance as in equation (1) - (2) where MS is the mobile station or also known as UE. MS_pos, RS_pos and BS_pos are the position for these three elements and RS_posdist or BS_posdist are the position distance for both RS and BS. The equations for RSSI in (3) – (4) are indicating for each UE-BS and UE-RS. Pt in equation is the transmit power, n for path loss exponent and e1 for normal log shadowing. Table 1 shows the summarized of LTE-A simulation parameters that used in this study.

Then, the new distance and RSSI will be recalculated after a channel was assigned. There are two choices either UE will connect to BS or RS based on the fixed conditions. Either a UE will connect BS or RS and then will receives its signal can be determined by using a predetermined algorithm [17]. The selection of the algorithms for RSSI based relay are explained as stated in equation (5) – (8) which will be using throughout this paper. Equations (5) and (6) are conditions for UE that connected to RS. Equation (5) is the condition for UE to connect to RS. If it is satisfied the equation (5) only then it will be handover to RS. If not, it equation (6) will be used. If RSSI for both RS and BS satisfied that equation then it will be handover to BS. Equation (7) and (8) show the probability UE connected to BS. UE will only handoff to BS if RSSI RS and RSSI BS in range of equation (7). If it is not satisfied equation

(7) then it will be passed to equation (8). When there is no problem with condition in equation (8), so it handover to RS will occurs.

MS_posRS_posdist = ((MS_pos - RS_pos)^2 + (MS_pos - RS_pos)^2) ^ (0.5) (1)

MS_posBS_posdist =((MS_pos - BS_pos)^2 + (MS_pos - BS_pos)^2) ^ (0.5) (2)

RSSI_BS = Pt_BS-10*n*log10 ((MS_posBS_posdist_min)) + e1 (3)

RSSI_RS = Pt_RS -10*n*log10 ((MS_posRS_posdist_min)) +e1 (4)

RSSI BS < RSSI RS & RSSI RS < -45 dBm (5)

RSSI BS < RSSI RS | RSSI BS > -90 dBm (6)

RSSI BS > RSSI RS & RSSI BS < -90 dBm (7)

RSSI BS > RSSI RS | RSSI RS > -45 dBm (8)

Table 1 : Simulation parameters.

Parameter	Explaination
Radius of BS	1 km
Power transmit, Pt (dBm)	BS = -90 RS = -20
Maximum no. of user (UE)	100
UE velocity (km/h)	110
Path-Loss Exponent (n)	3.1
Normal log shadowing (e)	6
Cell layout	7 cell/cluster

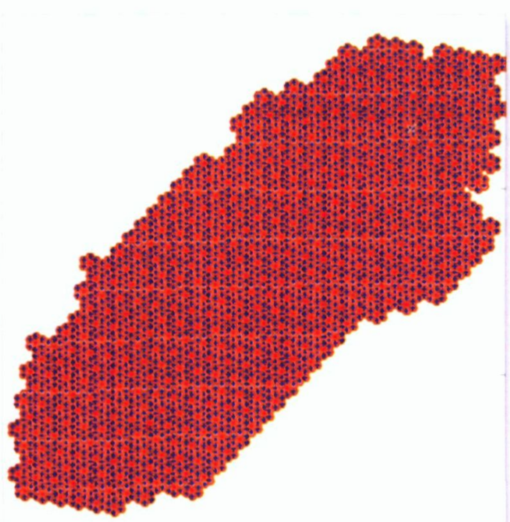

Figure 5 : The combination of hexagonal cells architecture for simulation part.

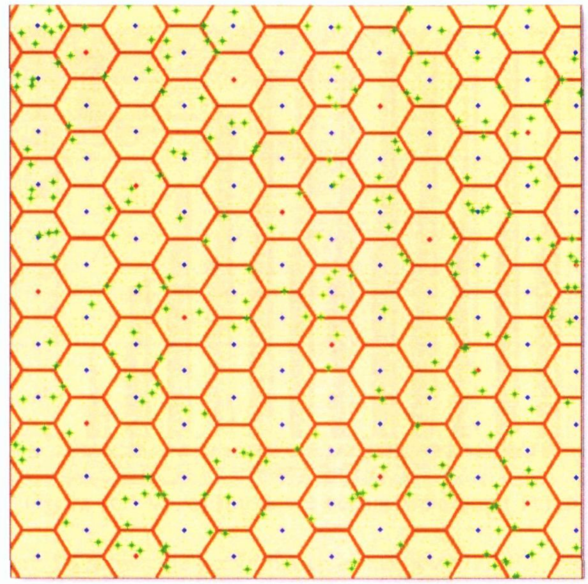

Figure 6 : Cell layout for random relays in cell architecture.

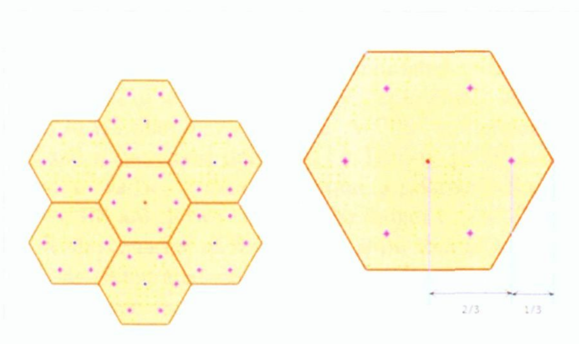

Figure 7 : Cell layout for six fixed relays per cell.

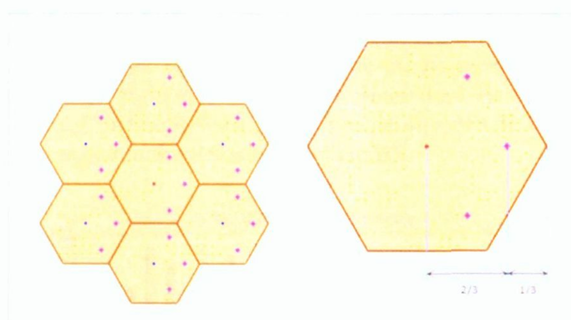

Figure 8 : Cell layout for three fixed relays per cell.

IV. Results, Analysis And Discussion

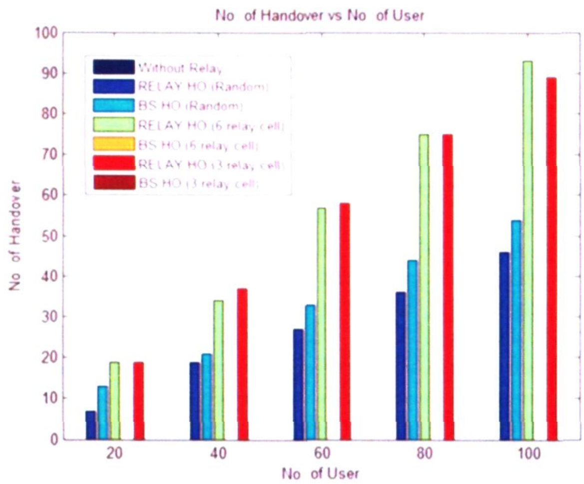

Figure 9 : No. of Handover versus No. of User.

For Figure 9, the numbers of handovers were evaluated, that are RS handover and BS handover for different number of user and different number of relay per cell. The speed of UE is fixed at 110 km/h with the simulation time is 2400 s. From figure above, it is indicating that all UEs handover to RS only for the both of fixed relays deployment, six relays per cell and three relays per cell. None of handover occurs at BS. It is because the remaining number of UE was terminated before it reached the maximum time of simulation. 93 UEs were handoff to RS and 7 users were terminated for the deployment of six relays per cell when the number of UE was set at 100. When the same number of user was applied to the three relays per cell it shows that are 89 UEs HO to RS occurred while the rest of UEs were terminated. This situation may occur due to the distance between UE-RS is nearer compared to distance between UE-BS. So, signal strength for RS is greater than signal strength for BS. However, for the random relay deployment it shows the different situation when the handover was higher at the BS compared to RS for the different set of maximum user. The reason behind this situation is the placement of the relay since it was generate randomly so the probability of the minimum distance between one UE to BS is higher than the minimum distance between an UE to RS. For no relay deployment, it is indicates that all UEs were blocked from make a call.

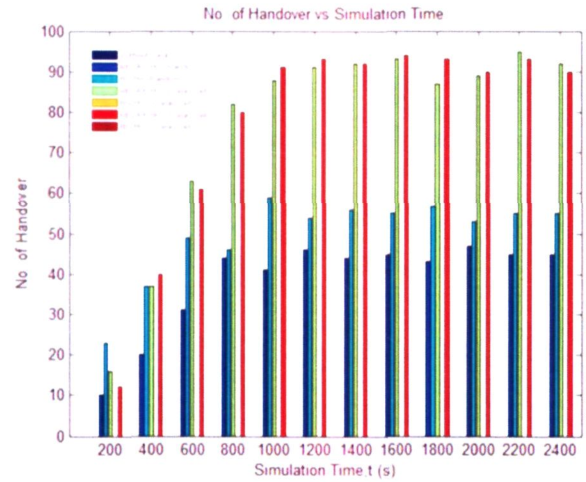

Figure 10 : No. of Handover versus Simulation Time.

Figure 10 shows the performance of handover for RS and BS in three different conditions of relay placement. The speed of UE was maintained at 110 km/h. while the transmitting power is -90 dBm and -20 dBm for each of BS and RS. None of users is able to make a call since the call is blocked. This situation occurs when the program was simulated with no relay deployment. For the random relay deployment shows more handoff to BS than handoff to RS. At 200th s, there are 10 HO to RS and it increased until 800th s. During 1000th s until the simulation reaches it maximum time, a relatively flat number of HO to RS are shown between the ranges of -40 dBm to -50 dBm. Both scenarios of fixed relays show that HO only occurs at RS as illustrated in Figure 10. At the beginning of simulation time the number of HO for six relays per cell is higher than HO for three relays per cell. This situation occurs again when the simulation time is about to expire. The slightly difference between the number of HO for fixed relays and random relays is due to the RS point. For the both of fixed relaying, each of their RS point is placed 2/3 away from each BS but for three relays per cell case all its three relays are located at the right side of each BS. Since the UEs move from North-East to South-West so the probability of UE will hand over its signal to the RS is higher than BS.

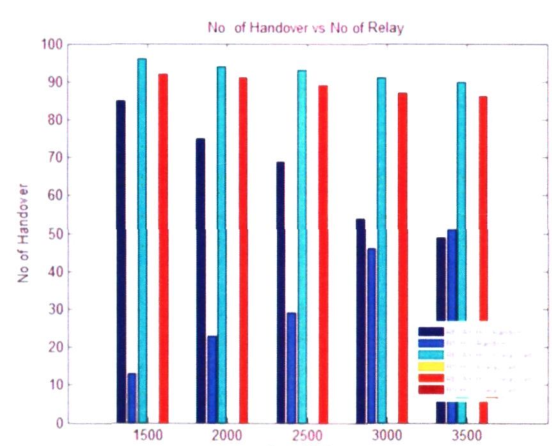

Figure 11 : No of Handover versus No. of Relay.

Figure 11 shows the obtained results for the different number of relay being used in these three cases of relay deployment. The number of handover for RS is higher compared to BS in random relay deployment for five different number of relay deployment. The RS handover is inversely proportional with number of relays. That can be seen at when the number of relay increases, number of handover will be decreased and vice versa. However when the simulation time is reaches its limit, the number of BS HO is more than number of RS HO as shown in the Figure 11. This can be due to the minimum distance of UE-BS is less than the minimum distance of UE-RS so an UE will handoff its signal to BS compare to RS. From the graph, it shows that when a relay was generated randomly the number of relaying is depends on the total number of relay deployed at a certain time. Increasing the number of relays will lead to the increment of HO. None of HO occurs at both of fixed relays per cell placement since most of the UEs signals are handoff to RS and there are several signal of users were terminated before the simulation time was finished. This is because a relay will just amplify the signal. So at certain area, a relay will strengthen the signal until it reaches another nearest relay. So when there is no nearest BS or RS that signal will be terminated.

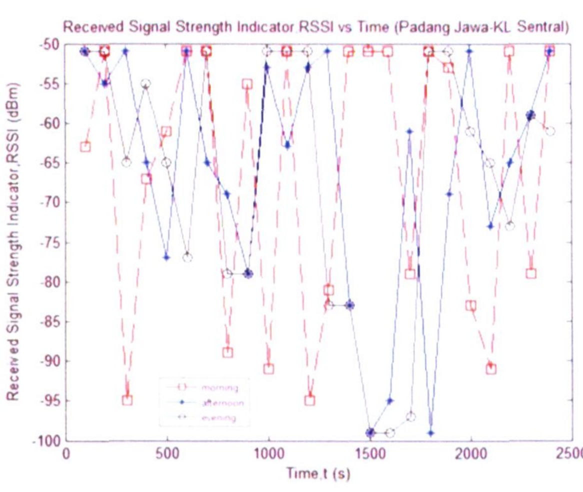

Figure 12 : Received Signal Strength Indicator, RSSI versus Time (measurement).

Figure 12 shows the signal strength obtained during doing the drive test from Padang Jawa to KL Sentral. The drive test was conducted three times daily for two days. The signal strength at the morning shows the moderate signal strength at most of the time. This situation occurs due to the peak hour for users to use the train to start their daily routine like go to work or school. At the afternoon and evening session of doing the drive test, it shows the worst signal strength readings at the same time interval. This may due to the in progress of construction works at the Subang Jaya station. Furthermore, in the evening, the data collection was taking right after the raining.

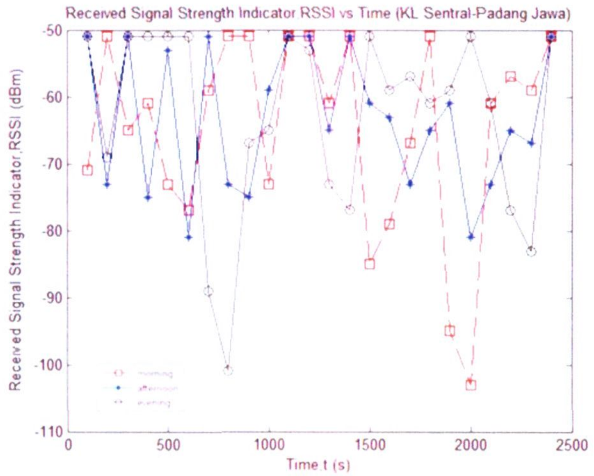

Figure 13 : Received Signal Strength Indicator, RSSI versus Time (measurement).

As depicted in Figure 13, most of the signal strength is at the good and moderate signal strength with RSSI readings between -50 dBm until -85 dBm for the afternoon session of doing the drive test from KL Sentral to Padang Jawa. During the evening session, the signal strength obtained is lower than -110 dBm. It may be caused by the light rain when train approaching Pantai Dalam station. For the data collection in the morning session, the signal strength slightly dropped from -51 dBm to almost -100 dBm and then dropped again to lower than -100 dBm, it may be happened due to the same construction works with the previous drive test from Padang Jawa to KL Sentral..

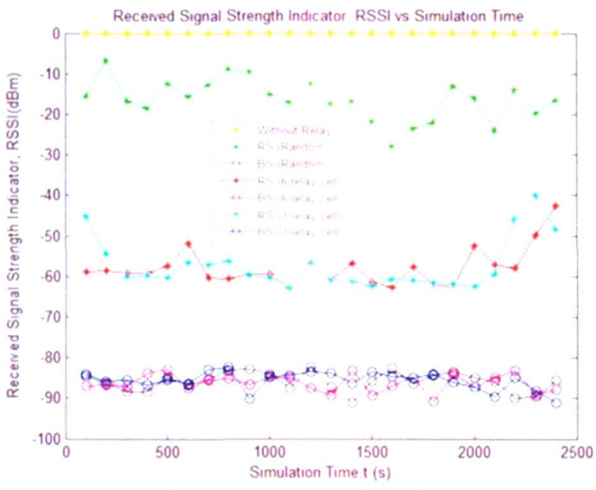

Figure 14 : Received Signal Strength Indicator, RSSI versus Simulation time.

Figure 14 shows the RSSI for relays deployment in simulation part for 2400 s. The readings for RSSI were taken before a channel was assigned to UE. The RSSI for RS in the random relays deployment indicate high readings with the average ranges of -10 dBm until -20 dBm. According to the standard RSSI from theoretical, the value better than -40 dBm is on the exceptional signal quality. Signals for six fixed relays per cell are on ranges between -50 dBm and -60 dBm for almost at all the period of simulation times. However their signal strength increases to the range of -40 dBm at 2200th s until 2400th s. So their readings for relay placement in six fixed relays per cell provide a good signal strength for most of the time interval and a very good signal when the simulation time is about to reach its limit. RSSI values for three fixed relays per cell indicate almost same signal strength as six fixed relays per cell. However RSSI for BS in random and fixed relays in the range of intermittent to no operation since their signal strength readings between the ranges of -80 dBm and -90 dBm. In addition, the RSSI is equal to zero when there is no relay was added in a cell. This is because the call that made by users were terminated before the simulation time was ended. The main problem in LTE-A network is the low signal achieved by cell-edge users. So relays act as an effective technique to solve this problem. So it can be assumed that by placing fixed relays in a certain distance from BS will provide good signal strength for users especially for cell-edges users compared to random relays deployment.

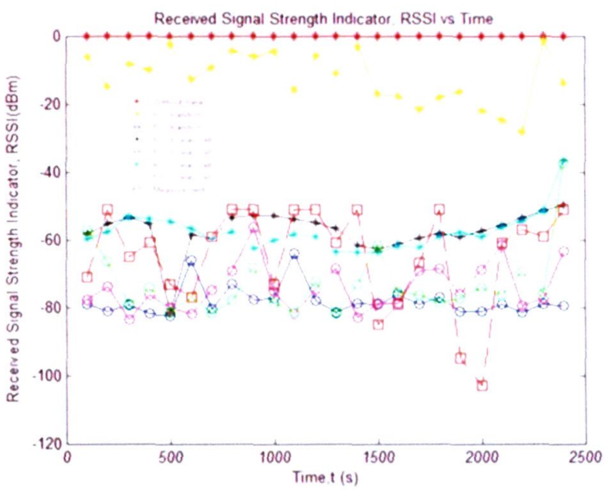

Figure 15 : Received Signal Strength Indicator, RSSI versus Time (simulation and measurement).

Figure 15 shows the RSSI readings for both measurement and simulation parts. These reading were obtained after a channel was assigned to an UE during the simulation within the same time duration as the time taken while doing the drive test from Padang Jawa to KL Sentral. The readings were depicted as in figure. For random relays placement their RSSI shows the exceptional signal strength during all the time of simulation. However, in fixed relays case RSSI for RS in both three relays and six relays per cell placement indicate the signal strength is in good signal quality since their RSSI readings between -40 dBm and -50 dBm. RSSI for BS in fixed and random relays show an improvement from unable to provide any signal in the Figure 14 to a marginal signal quality. At certain times there are some RSSI for BS reached the range of good signal quality with RSSI readings between -60 dBm to -70 dBm. A fluctuation of RSSI values occur during the measurement part. At the beginning and the end of the drive test was conducted their signal provide a good signal quality. Unfortunately the RSSI readings recorded change between these time intervals.

V. Conclusion And Recommendations For Future Work

The performance of relay deployment in LTE-A based on measurement and simulation has been studied in this paper. In measurement part, from the data collection obtained it can be seen there are various colour of marker along the path of drive test was done when the file of data collection was converted into Google Earth. So, the main aim is to deploy relay at the marker with red colour because the signal strength is low at these points. Simulation results shows the proposed fixed relays that are placed near the each cell-edge reduce the probability of dropped call from occur compared to no relay deployment. So by deploying the relay in LTE-A network can help in solving the problem of low signal strength at the cell-edges.

Since LTE-A is still remains as an ongoing project, so there are several recommendations may be proposed for future work. First recommendation is by applying the DF non-transparent relays. It will perform most of the completely established BS. So, an UE will handoff to RS when it farthest away from BS and closest to RS. So, it enables relay to maintain its own identity and broadcast control signaling to other UE. The other recommendation is by deploy relay in urban area scenarios with no obstruction so that the better coverage can be performed by relaying technique as expected. Next recommendation is place a relay at 3/4 away from the BS compared with 2/3 away currently. The distance between RS-BS will determine the RSSI values. Moreover, the relay placement for the 3 relays per cell can be improved by placing that three relays around the BS in a cell so that these relays not only focused on the right side of BS like current situation in simulation part. The system throughput of the network can be investigated as well as the outage probability when a relay is placed at a cell with a constant distance. In addition, to determine the strength of the signal also influenced by the transmit power, Pt. The Pt for simulation in this paper was set as -90 dBm for BS and -20 dBm for RS. So the different value for Pt can be considered in the future.

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