Non-Line-Of-Sight 2.6GHz Relay Backhaul Channel Performance: Field Test and Analysis

Yu Qian, Henrik Asplund, Jan-Erik Berg, Zhiheng Guo
Ericsson Research
Beijing, China[1,4], Stockholm, Sweden[2, 3]
yu.qian@ericsson.com, henrik.asplund@ericsson.com, jan-erik.berg@ericsson.com, zhiheng.guo@ericsson.com

***Abstract*—Relay technologies have been standardized in 3GPP long term evolution (LTE), and can be a useful tool for coverage extension in diverse deployments. The backhaul channel between the relay and its donor eNodeB is essential to the end-to-end relay performance. Recently there has been an increased interest in deployments with non-line-of-sight (NLoS) backhaul channel conditions. In this paper, the NLoS backhaul channel quality has been measured in the real field, and the results show that NLoS backhaul has obvious gain over donor-UE channel and can be good enough to support relay data forwarding. Rules of thumb for NLoS relay deployment are identified that can help to minimize the diffraction loss or to utilize the strong reflections to improve the channel quality.**

Keywords-component; LTE; relay; NLoS; backhaul

I. INTRODUCTION

Relay is a key new feature of long term evolution (LTE) [1][2], and is designed to provide cost-efficient coverage extension of the regular macro cellular network, thereby potentially improving data rates in poorly covered areas [3][4].

A relay uses wireless connection called backhaul to communicate with a source eNodeB, called the donor eNodeB, as is shown in Figure 1. It includes two parts, relay user equipment (UE) and relay eNodeB. The relay eNodeB provides access for the UEs in its coverage by processing the received signal from the UE using layer1-3 operations and forwarding the processed signal to the donor. It is vice versa for the downlink (DL) data from the donor to UE [1]. Since a relay uses wireless connection and the processing-forwarding mechanism requires lower backhaul channel quality than traditional direct amplifying repeaters, it is easier to deploy than a pico node with wire connection or traditional repeaters. Preferably, a relay is deployed with line of sight (LoS) to the donor. But clear LoS conditions can be quite difficult to achieve, and therefore the performance of the backhaul channel under partly non-line of sight (NLoS), i.e. light shadowing is of great interest. Our former work [3] shows that the relay with partly NLoS backhaul (partly blocked by a building skeleton under construction) can provide 8 Mbps UL throughput and 20 Mbps DL throughput, which is near to the theoretical limit.

However, in a dense urban environment, the coverage extension is most probably needed in the area with pure NLoS to the donor. In pure NLoS conditions the channel quality will be significantly reduced due to deep shadowing. The amount of quality reduction will determine to what extent NLoS backhaul relay deployments are feasible, thereby determining the

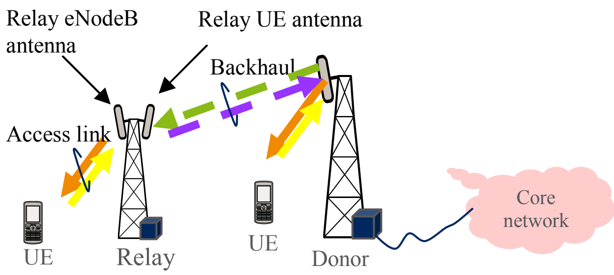

Figure 1 Overview of relay network architecture

usefulness of relays for coverage extension in dense urban areas. Relay antenna deployment positions, height and direction play the most important roles in the NLoS backhaul performance. There are a few pioneering papers targeting on this area, e.g. in [5], the relay antenna height gain of both LoS and NLoS backhaul have been investigated. A further step done in this paper is to optimize the usage of directional antenna for relay to capture the best performance.

The purpose of this paper is to report on a set of NLoS backhaul quality measurements in an urban area to understand the impact of relay UE antenna height, position and direction. The measurement method and environment description are introduced in section II, the results are shown and analyzed in section III, and the conclusions regarding the feasibility and optimization of NLoS relay deployments are provided in section IV.

II. MEASUREMENT METHODS AND ENVRIONMENT

The measurement is done in an area with modern industrial buildings, office buildings, apartments and open parks. An antenna is installed on the top of a 20 m high office building, connected to the donor eNodeB, and it is directed towards the far end of the street, see Figure 2, where building types, surface materials and heights are shown. The relay has been deployed in several different points, which are shown in Figure 3. The test points are categorized into four areas.

Area A: ~340 m to the donor with an irregular 16 m high industrial building between the relay and the donor, and a 23 m high office building in the back.

Area B: ~430 m to the donor, the front obstacle has a regular shape and is about 12~13m high and the building behind is at least 20m high.

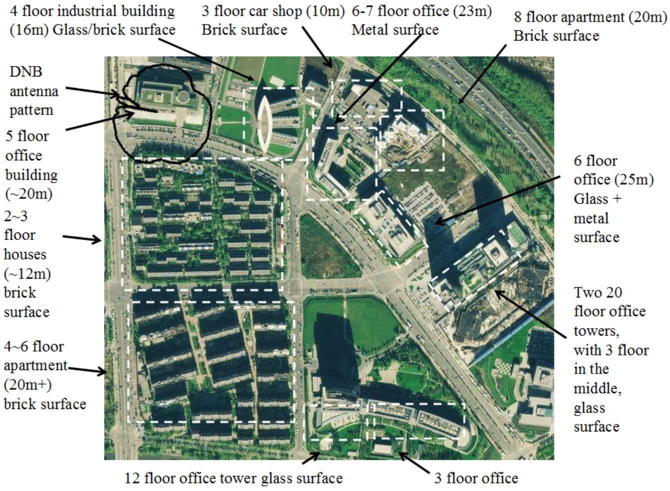

Figure 2 Measurement environments

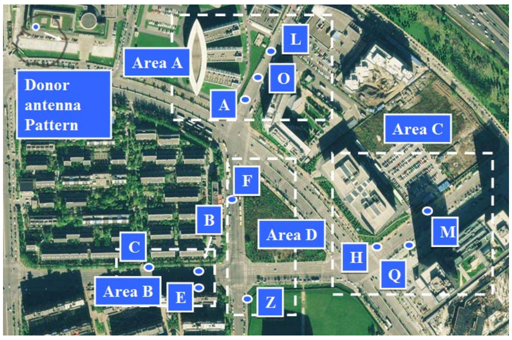

Figure 3 Relay test points

Area C: ~650 m to the donor with a 25 m high building between the relay and the donor, there are multiple reflections in this area.

Area D: 400 m (F) and 500 m (Z) to the donor, there are obstacles but no nearby reflections.

The backhaul link is measured at 2.6 GHz, the bandwidth is 20 MHz. The donor antenna is a Haitian HT355170 with ~65° to 75° half power beamwidth (HPBW), the relay UE antenna is a Kathrein 80010677 with 90° HPBW. Two Kathrein 80010431omni antennas are used as the common UE antennas to measure the channel quality without relay as the reference.

The relay UE antenna is mounted on a sky lift, which allows the antenna height to vary from 3m to 11m above the ground and supports 360° rotation in the horizontal plane. The relay UE antenna is connected with a 13m cable (~2dB loss) to the test equipment, and the common UE antenna is 2 m high and connected with a 2 m cable. The sky lift is mounted on a test vehicle to change the position of the relay UE antenna.

A Qualcomm TD-LTE dongle is used to measure the reference signal received power (RSRP), which is used as the metric of the backhaul channel quality. The RSRP is being logged during the 360° rotation. The relay UE antenna height has also been changed in the testing process for each point. By doing this, one can determine which antenna height and direction provide the best backhaul channel quality (highest RSRP from the donor).

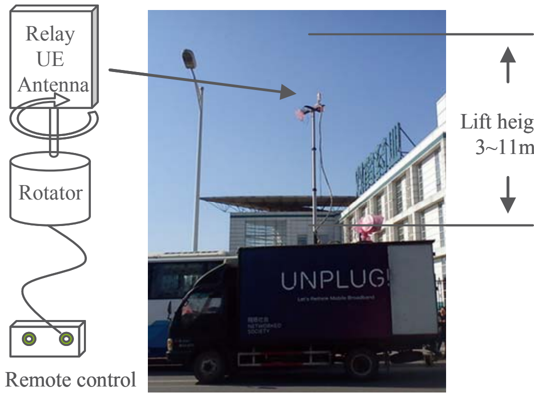

Figure 4 Test vehicle and sky lift

A further step is to compare the backhaul channel quality across the test points in the same area, in order to decide the best relay deployment position.

III. RESULTS AND ANALYSIS

A. Performance analysis within each test area

For each test point, a plot using polar coordinates of the antenna boresight direction angle, in radians, versus the radius RSRP, in dBm is drawn for each relay UE antenna height, to understand the best antenna direction, height and position, and the results are compared within each test area.

For area A, the test results are shown in Figure 5. It can be observed that when the test point is near the main street directly illuminated by the donor base station (see Figure 3), it has the best backhaul channel quality, e.g. point A. This is because that it has almost LoS backhaul to the donor. For point O, it is further from the illuminated street and also in deeper shadow of the front irregular building, and the RSRP is at least 3 dB lower than point A. For point L, since it has the most serious shadow, the RSRP is the lowest.

Furthermore, the impact of the reflection can be observed. E.g. for point A, facing the donor and facing the reflection have similar RSRP (1dB higher for donor), when the antenna height is 11m. For point O, facing the reflection has 1dB gain over facing the donor. For point L, the reflection gain is even larger, the two highest RSRP angles both direct to reflections, since it is in the shadow of a nearby building in the donor direction.

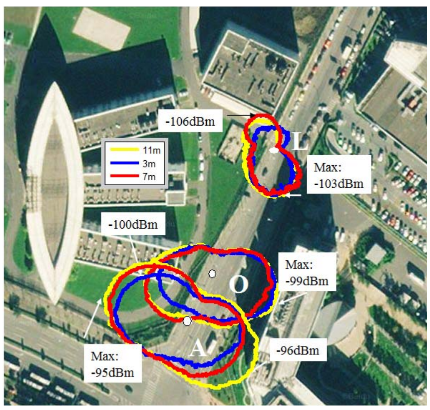

Figure 5 RSRP for area A

It is also obvious that the RSRP most often increases with the antenna height. This coincides with the conclusion of [5]. This rule applies for both diffraction and reflection.

In area B (Figure 6), the first conclusion is to place the relay UE antenna as far as possible from the front obstacle, and as high as possible. E.g. the best backhaul channel is observed at point E, which is further from the shadowing buildings and in an almost LoS status, see Figure 7.

The second one is to utilize the "tunnel" illuminated by the donor. E.g. there is no nearby obstacle between point C and the donor and this forms a "tunnel", and the signal from the donor could propagate along it with less loss, see Figure 3. So point C also has much higher RSRP than point B.

For both point C and E, pointing the relay UE antenna towards the donor leads to larger RSRP. But for point B, pointing the relay UE antenna towards the back reflection leads to larger RSRP.

The antenna height gain is more obvious in this area. In the donor direction, 11 m height leads to the largest RSRP, except for point B, because even its highest height is still in the deep shadow. In the reflection direction, both for point B and C, 7 m height leads to the largest RSRP, even higher than 11 m. This could be caused by different reflection surfaces (brick vs. glass windows) at different heights of the back apartment.

For area C, one LoS point (H) and two NLoS points (Q and M) have been tested, and the LoS→NLoS switching performance has been tested by moving the relay UE antenna from point H to NLoS along the street. Figure 9 shows that the RSRP curve drops sharply to 17 dB lower, and this is done within about 2 m distance.

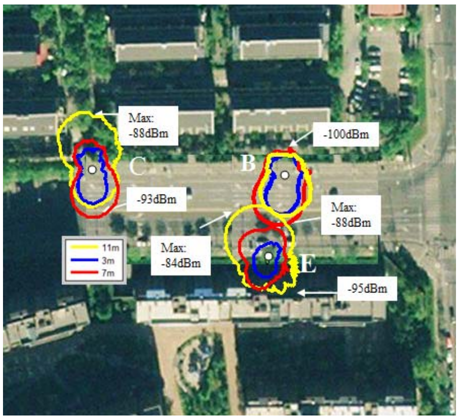

Figure 6 RSRP for area B

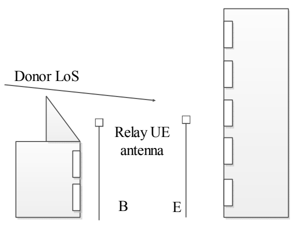

Figure 7 Illustration of propagation envrionement in area B

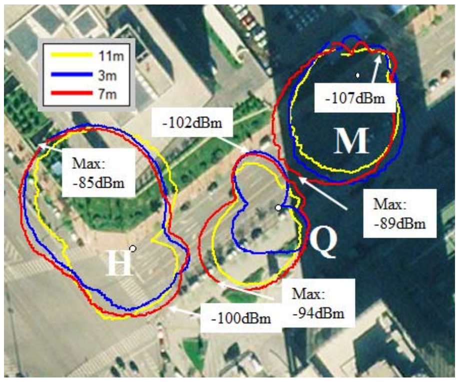

Figure 8 RSRP for area C

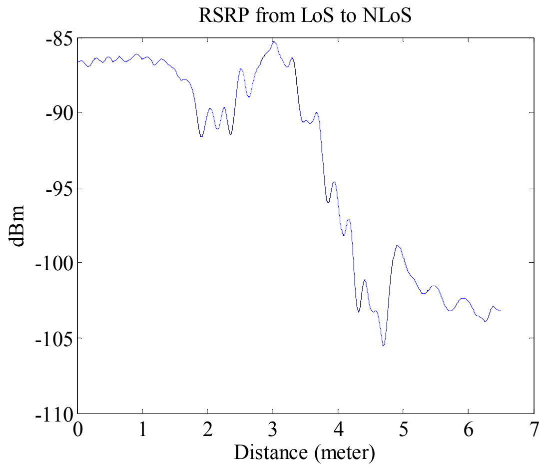

Figure 9 RSRP variation from LoS to NLoS

Figure 10 Reflection for area C

Point H has the largest RSRP with no doubt, since it is LoS. For point Q and M, their highest RSRP are only 4 and 9 dB lower than LoS value. The highest RSRP is achieved when the antenna is pointing to south-west. The reason why they see such high RSRP at this direction is due to the reflection. In the south west of the point M and Q, the 12 floor glass surfaces building shown in Figure 2 and Figure 10 serves as a perfect reflection, due to its position, its reflection angle and its smooth surface.

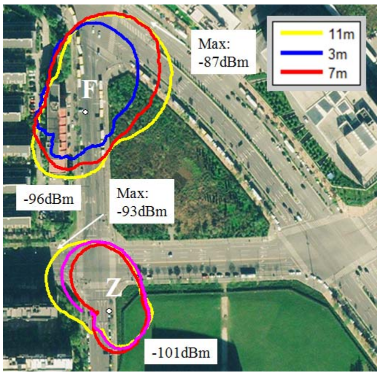

Figure 11 RSRP for area D

Figure 12 Reflection direction for area B

For area D, the two points are with a large open area on one side, and the obstacles on the other side. Point F has a nearby and high obstacle (4 floor building in the left) between it and the donor, and point Z has no nearby obstacle.

It is clear that, for point F, facing the relay UE antenna to the main reflection leads to quite high RSRP, and for point Z, facing the antenna to the donor leads to high RSRP.

When comparing point Z and point M, it could be concluded that the reflection from the 12 floor high building is higher for M than Z. From Figure 10, it is also clear that point M obeys geometric rule well. For area B, the major reflection angle also obeys the geometric rule, according to both Figure 6 and Figure 12. This means that the reflection of the signal at 2.6 GHz obeys geometric rule in general.

B. Antenna height, direction and overall gain analysis

The antenna height, directional and overall gains are compared among all the points in this section, to understand the general impact of height and direction.

Figure 13 shows the relay UE antenna height gain in dB, the definition of it is:

$$Gain_h = RSRP_{max} - RSRP_{\max\_3m} \qquad (1)$$

$RSRP_{max}$ refers to the maximum RSRP in dBm achieved for all the possible antenna heights and directions of a given relay position, $RSRP_{\max\_3m}$ refers to the maximum RSRP in dBm achieved for 3 m height of the same given position.

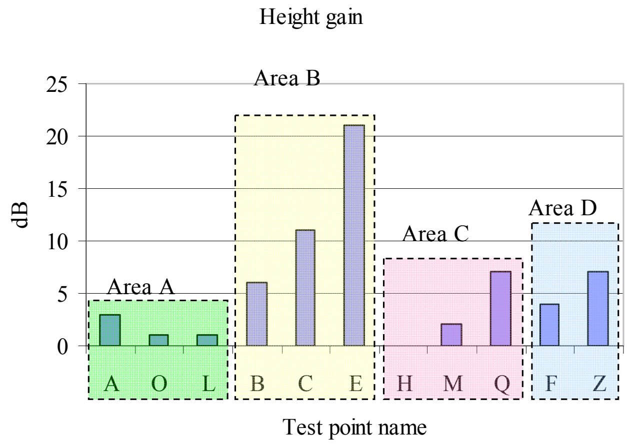

Figure 13 Relay UE antenna height gain for each test point

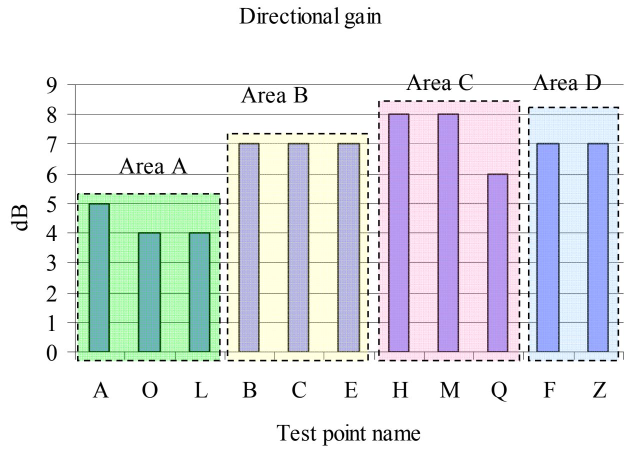

Figure 14 Directional gain for each test point

The highest relay UE antenna height gain is seen for point E in area B, where there are front short obstacles which block the direct signal incidence at 3 m height, but not at higher heights.

The lowest NLoS relay UE antenna height gain is seen in area A, point O and L, since there are high nearby obstacles which shadow all the heights. It should also be noticed that there is no height gain for point H, which has LoS to the donor.

For point A, F and M, there are no nearby obstacles in the major signal incoming direction, so the relay UE antenna height gain is also small, 2 ~ 4 dB. For other points, e.g. point B, C, Q, the height gain varies from 6 to 11 dB, the antenna has to be high enough to receive the almost LoS signal or strong reflected signal for them.

Figure 14 shows the directional gain for each test point, and the definition of the gain in dB is:

$$Gain_d = RSRP_{\max} - \overline{RSRP_{sameheight}} \qquad (2)$$

$RSRP_{\max}$ definition is the same as in (1), and $\overline{RSRP_{sameheight}}$ is the average value in dBm of the RSRP over all directions of the same height as $RSRP_{\max}$ and at the same given position, in order to emulate an omni directional antenna.

It could be seen that for area B, C and D, the directional gain is most often between 6 to 8 dB, but for area A, and it is around 4 dB. The reason for lower directional gain in area A is that there are always two major signal incoming directions with similar RSRP, and this reduced the difference between the maximum RSRP and the averaged one.

Figure 15 shows the overall optimum relay UE antenna gain in dB, the definition of it is:

$$Gain_o = RSRP_{max} - \overline{RSRP_{3m}} \quad (3)$$

$RSRP_{max}$ refers to the maximum RSRP in dBm achieved for all the possible antenna heights and directions of a given relay position, $\overline{RSRP_{3m}}$ refers to the average value in dBm of the RSRP on all directions of 3 m height of the same given position, in order to emulate an omni directional antenna.

The highest gain between 13 to 23 dB is seen for area B; and the lowest gain around 5~8 dB is seen for area A, this is because that the points in area A are either in deep shadow for all heights, e.g. point L, or only in light shadow that the RSRP at low height is still high, e.g. point A.

As for area C and D, the gain is between 8 and 13 dB, and the gain comes from strong reflection for most of the points.

Comparing Figure 13, Figure 14 and Figure 15, it can be concluded that for most areas (A, C and D), the major overall gain comes from optimized direction, and for area B, the gain comes from both direction and height.

In the test, it is also observed that for area A, B, C and D, the maximum NLoS (excluding point H) RSRP are -95 dBm, -84 dBm, -89 dBm and -87 dBm. With 500 m inter-site distance (ISD) for macro eNodeBs, the relays will seldom be placed more than 300 m from a donor. The RSRP for <300 m NLOS deployments should likely be some dB better than in the current 340-650 m measurements. This hints that NLoS backhaul channel quality can be quite good.

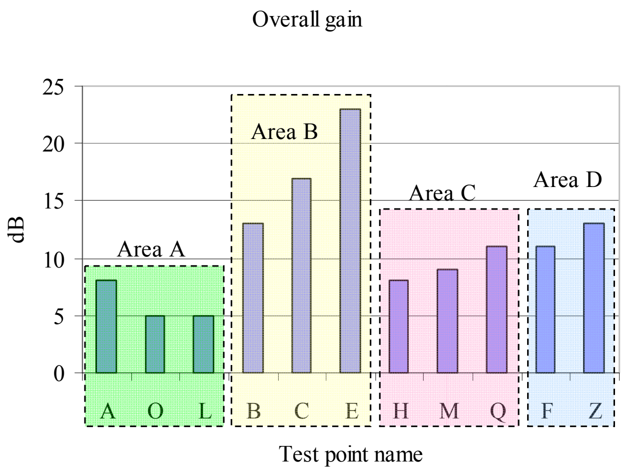

Figure 15 Optimum relay UE antenna gain

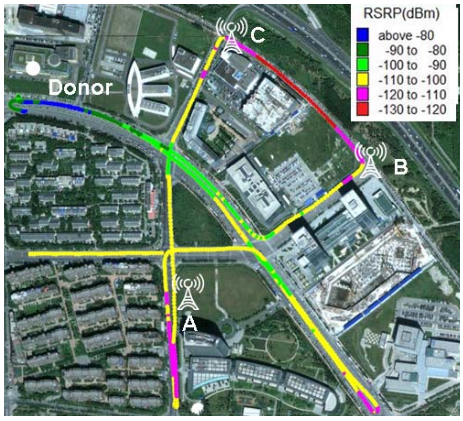

Figure 16 UE RSRP without relay

Figure 16 shows the RSRP without relay, where the three areas with poor coverage (RSRP< -110 dBm) are marked with pink and red. Coverage improvements for UEs in these areas should be possible by deploying relays in e.g. points A, B, or C, since point C has LoS to the donor and point A, B are NLoS with around -90 dBm RSRP for the donor-relay link, and it can be expected that the relay-UE links are considerably better than the donor-UE links. It should be mentioned that relay could also be used to improve indoor coverage from outdoor in a similar way. However, the capacity impact of the relay deployment is beyond the scope of this paper.

IV. CONCLUSIONS

The measurements support the conclusion that the donor-relay channel can have sufficient quality also in NLoS conditions, provided that the relay deployment is not too strongly shadowed, and it has obvious gain over donor-UE channel. This can be achieved by combining the three methods: (1) optimizing the relay deployment by choosing a position far from the intermediate obstacles such that the diffraction loss is limited or with strong reflection, (2) using a high antenna height (3)pointing the antenna towards the strong diffraction or reflection. These simple rules can help to optimize relay performance in future deployments.

REFERENCES

[1] E. Dahlman, S. Parkvall & J. Sköld, “4G LTE/LTE-Advanced for mobile broadband,” Elsevier Ltd., Publication, chapter 16.

[2] D. Astély, E. Dahlman, A. Furuskär, Y. Jading, M. Lindström, and S. Parkvall, “LTE: the evolution of mobile broadband,” IEEE Communications Magazine, vol. 47, no. 4, pp. 44–51, April 2009.

[3] Gan Jiansong, Guo Zhiheng, Fan Rui, Liu Weihong, Wang Hai, K. Sandlund, Liu Jianjun, Shen Xiaodong, Liu Guangyi, “LTE in-band relay prototype and field measurement”, published in IEEE VTC 2012 spring.

[4] R. Pabst, B. H. Walke, D. C. Schultz, et al., “Relay-based deployment concepts for wireless and mobile broadband radio,” IEEE CommunicationsMagazine, vol. 42, no. 9, pp. 80–89, 2004.

[5] I. Rodriguez, C. Coletti, T. B. Sørensen, “Evaluation of potential relay locations in a UrbanMacro-cell scenario with applicability to LTE-A”, published in IEEE VTC 2012 spring.