LTE In-Band Relay Prototype and Field Measurement

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Abstract— **Relaying is a feature defined in LTE Release 10 to provide coverage in new areas and/or to improve cell-edge throughput. For the purpose of investigating relay's performance in a real network, an LTE TDD in-band relay prototype was developed. Based on this prototype some field measurements were conducted using LTE Release-8 terminals. Both indoor scenarios and outdoor scenarios were tested. Measurement results show that relays (once properly deployed) provide good coverage in the coverage holes of a donor eNB. Besides coverage extension, relays can also improve data rate in the poorly-covered area of a donor eNB, i.e. cell edge. The throughput of a terminal served by this relay prototype reaches around 8 Mbps in the uplink and 20 Mbps in the downlink. Regarding latency, given uplink data is always scheduled, the measured round-trip time via the relay is around 10 ms larger than that directly via the donor eNB.**

I. INTRODUCTION

The long-term evolution (LTE) [1] as defined in the 3rd generation partnership project (3GPP) is a major step towards international mobile telephony (IMT)-Advanced. It provides a peak rate of 300 Mbps and a minimum delay of less than 5 ms. With LTE end users are expected to have superior experience on the go.

In the initial installation phase, LTE can be deployed for hot spots first. However with the increasing number of LTE subscribers and the increasing demand for high data rates, there will be increasing requirements on LTE to provide service anywhere. These areas include that with unfavorable radio propagation conditions like dense urban, rural area and indoor.

In order to cope with poor radio propagation conditions, 3GPP specified a new network node (relay) in Release 10 [2], [3]. By means of inserting an intermediate node (relay), the radio link between a base station (a.k.a. eNB) and a terminal (a.k.a. UE) is divided into two links. The link between a donor eNB (an eNB that provides access for relays) and a relay is denoted backhaul link or Un interface, while the link between a relay and a terminal is denoted access link or Uu interface. Via proper deploying of the relay, both the backhaul link and the access link can be made with better propagation condition compared with the direct link, and hence the end-to-end performance can be improved compared to the case without relay. Computer simulations have showed that introducing relays leads to gains in both cell-edge user throughput and aggregated cell throughput [4], [5].

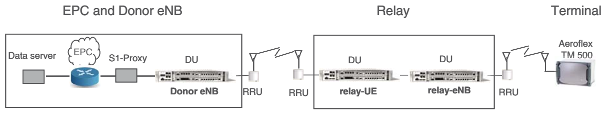

Fig. 1. System architecture of the prototype

This paper looks into feasibility and real-life performance of 3GPP LTE relays via prototype development and field measurement. The prototype is a time-division duplex (TDD) system working at 2.3 GHz with 20 MHz bandwidth. The design of the prototype follows 3GPP in-band relay (Type 1 in [6]) design principles though details may differ from that. LTE Release-8 terminals can access the evolved packet core (EPC) via the relay prototype and works in both uplink and downlink. So the results in this paper indicate the real-life performance that an end user can experience in a relay-assisted LTE network. Those features make this work different from previous relay test beds [7], [8]. Though it is a TDD relay, the general conclusion should in principle apply for an FDD relay, as a TDD relay and an FDD relay share the same design principles, e.g. all radio protocols terminated at relay, half duplex between backhaul and access by means of multicast broadcast single frequency network (MBSFN) configuration.

This paper is organized as follows: Section II reviews some important designs of the prototype and gives an indication of the expected throughput performance. Section III provides measurement setup and measurement results. The measurement results include reference signal received power (RSRP), uplink throughput, downlink throughput and latency. The measured scenarios include outdoor and indoor. Section IV gives some concluding remarks.

II. SYSTEM DESIGN AND IMPLEMENTATION

As shown in Fig. 1, the system consists of one donor eNB, one relay and one LTE Release-8 terminal (Aeroflex TM500 is used in field tests). The relay consists of two parts (relay-eNB and relay-UE) which are connected to each other via Ethernet.

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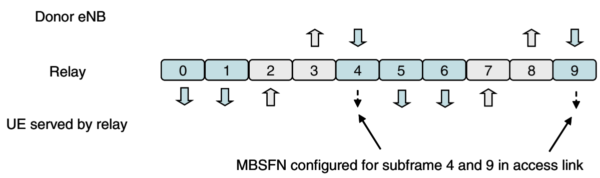


Fig. 2. Backhaul-access partitioning

A new sub-node called S1-Proxy is introduced to serve as a proxy for relay towards the core network. Like Type 1 relay in 3GPP, the relay prototype is an independent cell as seen from its subordinate UEs.

Functionality-wise the system contains mainly two parts: physical layer and protocol stack. The physical layer of an in-band relay should guarantee no mutual interference between relay-UE and relay-eNB, and it should also provide backward compatibility to Release-8 terminals. The protocol part should handle packets correctly for both user plane and control plane and guarantee Release-8 terminals can access EPC via relay.

A. Physical Layer Design

Only TDD configuration 1 is implemented in the prototype. To build an in-band relay, backhaul link and access link should use distinct subframes in order to avoid mutual interference. To make relay backward compatible to LTE Release-8 terminals, we use the same trick as in 3GPP [2]: configure some downlink subframes in relay cell to be MBSFN subframe, and use the multi-cast part of these subframes for backhaul downlink transmission. As subframe 0, 1, 5 and 6 can not be configured as MBSFN subframe, subframe 4 and 9 are configured as MBSFN. To fulfill Release-8 hybrid ARQ (HARQ) timing, uplink subframe 2 and 7 are used for access link while subframe 3 and 8 are used for backhaul link. The backhaul-access partitioning is illustrated in Fig. 2. This partitioning leads to a maximum end-to-end lossless throughput of 8.77 Mbps in uplink, with modulation and coding scheme (MCS)=23 for backhaul, MCS=22 for access link and up to 16 QAM for both links. A relay may fully occupy all backhaul subframes, if its subordinate terminals demand large traffic. In that case the resources in the donor eNB will be reduced compared with a normal eNB.

As the standardization of relay physical downlink control channel (R-PDCCH) in 3GPP has not been finalized during the development of the prototype, R-PDCCH used in this prototype is not the same as R-PDCCH in 3GPP. R-PDCCH in this prototype resides in the second orthogonal frequency-division multiplexing (OFDM) symbol of a backhaul downlink subframe. It has the same format as LTE Release-8 PDCCH, e.g. spanning the entire bandwidth. Each control region in backhaul, access and donor cell occupies one OFDM symbol. With this design, relay physical downlink shared channel (R-PDSCH) for backhaul contains 12 OFDM symbols, which limits the maximum MCS on backhaul to 27. Together with the fact that only subframe 4 and 9 are used for backhaul, backhaul becomes the bottleneck in the downlink and the maximum downlink end-to-end throughput is 25.5 Mbps with two-stream transmission.

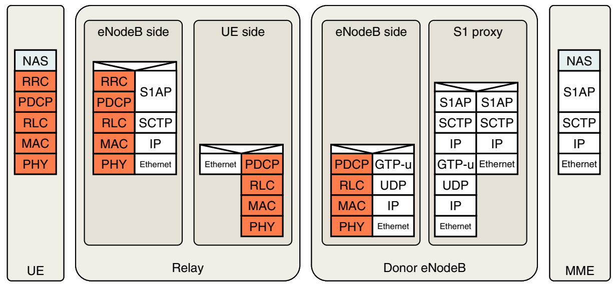


Fig. 3. C-Plane protocol stack

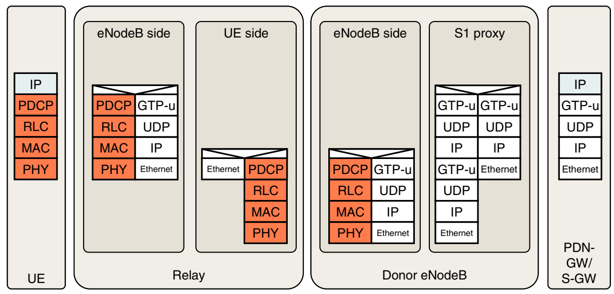


Fig. 4. U-Plane protocol stack

B. Protocol Stack

As shown in Fig. 3 and Fig. 4, the protocol stack of the prototype is somewhat different from that in 3GPP [9]. The main difference is that relay is divided into independent eNodeB part and UE part which are connected to each other via Ethernet. A new node called S1 proxy is introduced to serve as a proxy between relay and core network. The advantage of this architecture is its implementation simplicity, as existing codes for eNodeB protocol stack and UE protocol stack can be reused directly.

III. Field Measurement

A. Measurement Setup

Fig. 5 provides an overview of the measurement setup. Donor eNB is installed on top of Bldg. A (six-floor high). Relay-UE and relay-eNB are installed on top of Bldg. B (four-floor high). Donor eNB and relay-UE are pointing to each other and around 460 m apart. Between donor eNB and relay-UE there is an eight-floor building under construction. At the time of measurement, the frame of the building is finished, while wall and windows are not yet installed. So the backhaul link is neither line of sight (LOS) nor fully blocked. Relay-eNB is pointing to the east. Outdoor measurement was conducted along the road clockwise as shown in the figure, while indoor measurement was conducted in a canteen in the north-east direction of relay-eNB.

Donor eNB, relay-UE and relay-eNB use the same type of antenna (Kathrein 80010541 [10]). It is directional cross-polarized antenna with two antenna ports. The transmission

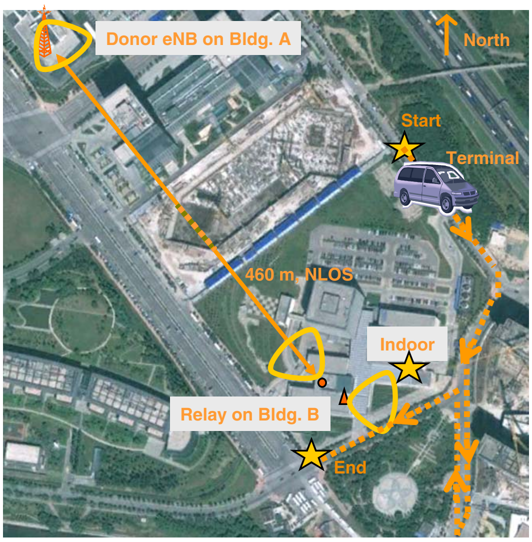
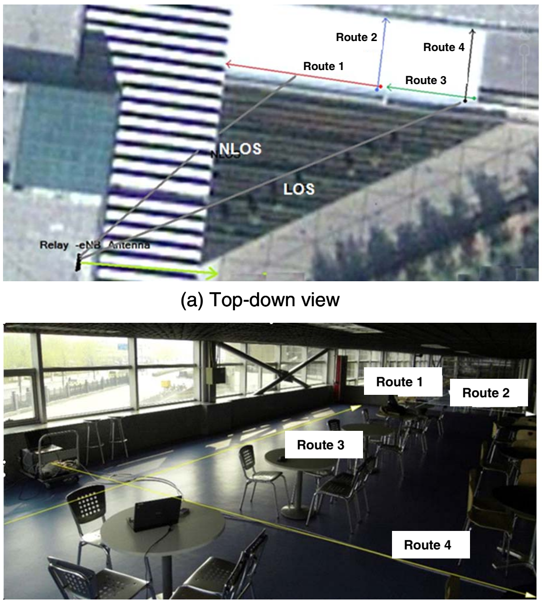


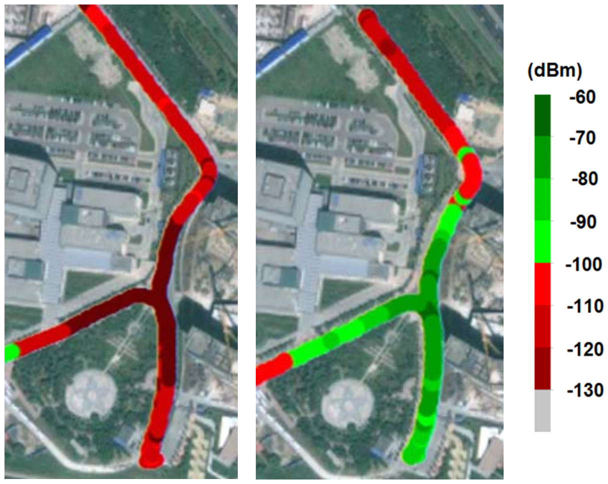
Fig. 5. Outdoor measurement setup



(a) Top-down view

(b) Indoor view

Fig. 6. Indoor measurement setup



(a) From donor eNB (b) From relay

Fig. 7. Outdoor RSRP map

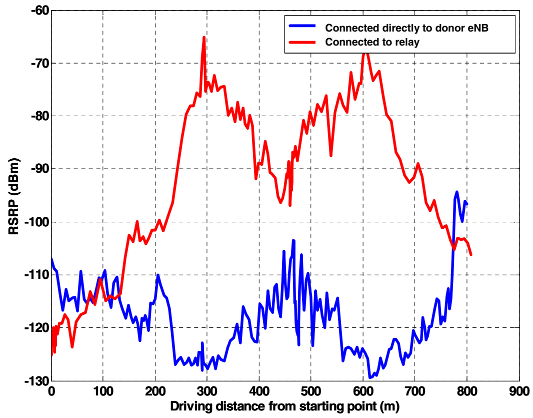


Fig. 8. Outdoor RSRP curve

power of donor eNB, relay-UE and relay-eNB are all 43 dBm per antenna port. Iperf [11] is used to generate user datagram protocol (UDP) traffic. For uplink throughput test, UDP packet is sent from the terminal and received at the data server in the core network. For downlink throughput test, UDP traffic is sent from the data server and received at the terminal.

The canteen for indoor measurement is on the second floor, 50–80 m away from the relay-eNB. The canteen has large windows towards the direction of the relay. The width of the canteen is around 12 m. The terminal moves along the four routes as shown in Fig. 6. In the start part of Route 3 and Route 4, LOS exists between the terminal and the relay-eNB. However for Route 1 and Route 2, it is always non LOS (NLOS) due to the blocking of the roof.

B. Outdoor Measurement Results

Fig. 7 provides RSRP experienced at the terminal at different locations. To have a more clear comparison for with/without relay cases, Fig. 8 plots RSRP into curves. The start point and the end point are as shown in Fig. 5. In the east of Bldg. B, the RSRP from the donor eNB is less than -120 dBm due to the blocking of Bldg. B. In this area, the relay can improve RSRP to between -70 dBm and -80 dBm, which means around 50 dB RSRP improvement.

Fig. 9 provides uplink UDP throughput performance. To have a stable uplink, the maximum uplink MCS is set to 20 for the both donor eNB and the relay eNB , which limits the maximum Layer 1 throughput of the relay to 7.98 Mbps instead of 8.77 Mbps. When a terminal connects directly to the donor eNB, the uplink application-layer throughput can

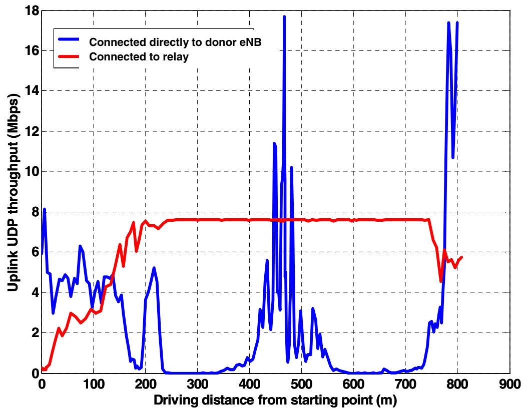


Fig. 9. Outdoor uplink throughput

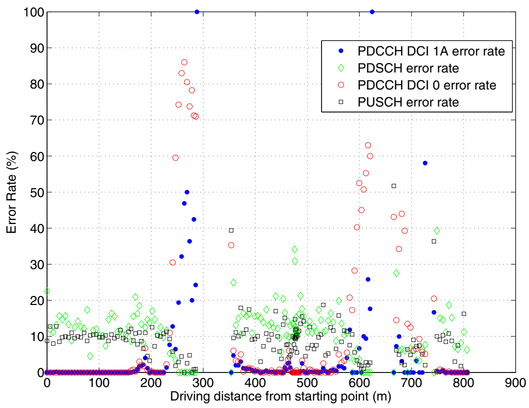


Fig. 10. Error rate for PDCCH, PDSCH and PUSCH

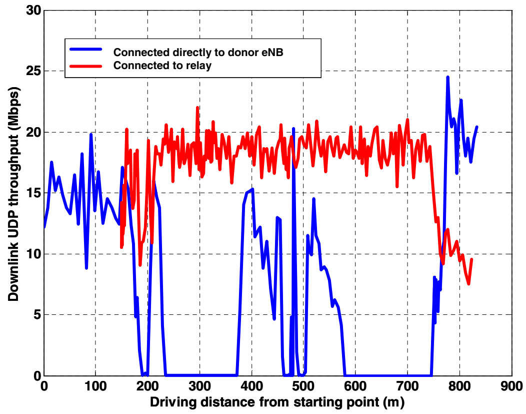


Fig. 11. Outdoor downlink throughput

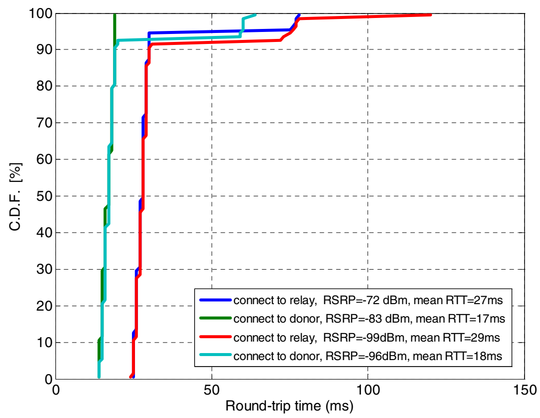


Fig. 12. Round-trip time from donor eNB and relay

reach around 16 Mbps for good-RSRP area. However when the terminal moves to the east of Bldg. B, the throughput drops to zero. When the relay is turned on and the terminal connects to the relay, throughput at the east of Bldg. B can be improved to 7.6 Mbps.

To analyze whether the relay improves coverage or throughput, the error rate performance for control channel and data channel is analyzed when the terminal is connected to the donor eNB, and results are summarized in Fig. 10. For the area with good RSRP, PDCCH error rate is close to zero, while PUSCH and PDSCH error rate is around 10 percent due to link adaptation. For the east of Bldg. B, the RSRP is lower than -125 dBm, and PDCCH performance drops significantly to 100 percent error rate (error rate for data channel is still OK). Then the terminal was released by the donor eNB. In this area, there is no coverage from the donor eNB. So in this area, the relay provides coverage extension. For other area, the donor eNB can provide basic coverage, and the relay mainly serves as throughput booster if any.

For downlink, transmission mode 2 is used at the donor eNB for terminals as it has better performance than transmission mode 3 in low signal-to-interference-plus-noise ratio (SINR) area, which is our most interesting area. For relay, both the backhaul link and the access link use transmission mode 3. The throughput comparison for the donor eNB and the relay can be found in Fig. 11. In the area with zero throughput, PDCCH can not be detected by the terminal due to too low RSRP, and this area is control-channel limited. In this area, the relay improves the throughput from 0 to around 20 Mbps. The throughput does not reach the maximum throughput (25.5 Mbps) as backhaul channel quality is not good enough to support the maximum MCS. For the area of driving distance 350–580 m, control channel from donor eNB is correctly detected though throughput from the donor eNB is usually less than 15 Mbps. In this area, the relay provides around 20 Mbps throughput, which shows relays can also increase throughput in low-data-rate area from a donor eNB (not only provide coverage extension). The relay provides higher throughput because the poor direct link is divided into two good links which support two-stream transmission during this measurement.

One common concern for relays is the latency introduced

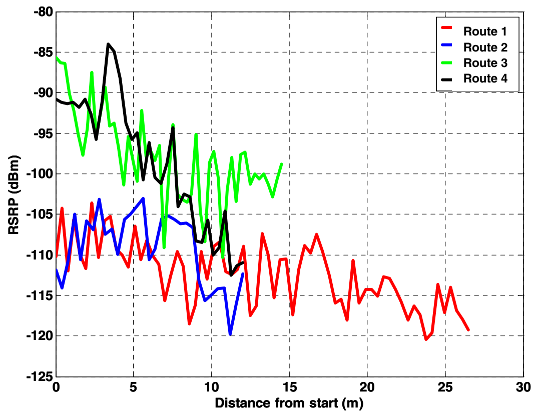


Fig. 13. Indoor RSRP

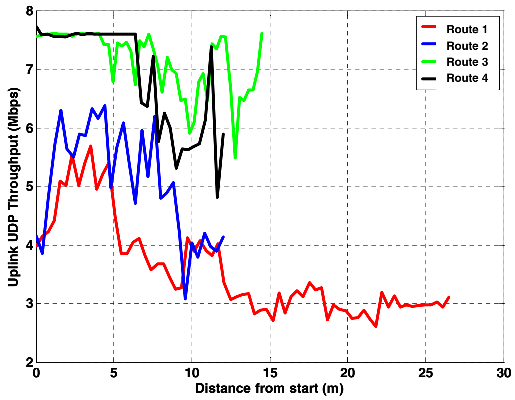


Fig. 14. Indoor uplink throughput

by an extra hop over the air. Fig. 12 provides the round-trip time distribution between the terminal and the data server in core network. Ping of 32-byte packet is used, and locations with different RSRP are tested. Results show that the relay introduces an additional delay of around 10 ms. In this prototype, uplink data is always scheduled. So UE does not need to send scheduling request before sending uplink data. If relay needs to send scheduling request before uplink data transmission, the additional delay should be larger.

C. Indoor Measurement Results

There is no coverage from the donor eNB in the canteen, so only performance from the relay is provided. Performance results include RSRP, uplink throughput and downlink throughput in Fig. 13, Fig. 14 and Fig. 15 respectively.

Measurement results show that when relay is turned on service is always available for the tested routes. Among all tested locations, the maximum RSRP is -85 dBm and average RSRP is -105 dBm; the maximum uplink throughput is 7.6 Mbps and average uplink throughput 5.4 Mbps; the maximum downlink throughput is 21.4 Mbps and average downlink throughput 16.9 Mbps. The performance provided by the relay to the indoor area is quite good.

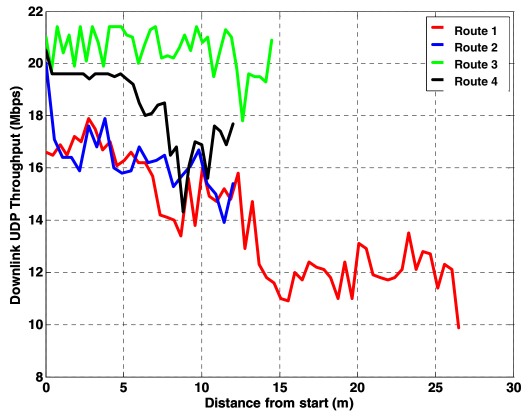


Fig. 15. Indoor downlink throughput

IV. Conclusions

Field measurement shows that LTE in-band relays work in reality and can provide services and good performance to LTE Release-8 terminals. In the measurement end-to-end throughput via the relay reaches around 8 Mbps in the uplink and around 20 Mbps in the downlink. Tests in different scenarios show relays work with both LOS and NLOS backhaul. Both indoor and outdoor terminals can benefit from the deployment of relays. Relays provide not only coverage extension to no-coverage area from a donor eNB but also throughput enhancement in poorly-covered area from a donor eNB. Given uplink data is always scheduled, the additional delay introduced by relay in round-trip time is around 10 ms.

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