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Title: Parameters Determining Relay based System Performance Gain
Document for: Discussion

1. Introduction

Different deployment scenarios have been considered in [2-9] showing widely varying system performance gains from using relays or repeaters. This contribution summarizes system parameters/characteristics impacting relay/repeater induced system performance gains. Also quantified is the mitigation of in-band relay enhanced system performance due to overhead from the TDD aspect of in-band relays and the division of macro eNB downlink resources between UEs it serves (UE1) and UEs served by relays (UE2).

2. In-Band Relay Description

Typically, an in-band Relay Node (RN) cannot concurrently Tx and Rx in the same DL frequency band (F1) of a carrier, so the eNB→RN and RN→UE2 links on F1 are time multiplexed. Similarly, the RN→eNB and UE2→RN links are also time multiplexed in the UL frequency band F2. In other words, RN operates as a FDD-eNB from UE2 perspective, but RN has to support TDD operation (Tx & Rx) in both DL and UL carriers. The preferred Relay frame structure is based on utilizing MBSFN subframe signaling for in-band relay operations (RN→UE2, eNB→RN in the DL and UE2→RN, RN→eNB in the UL).

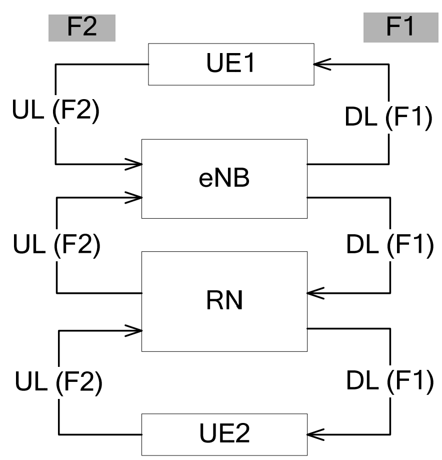

Figure 1 – Conventional Duplexing Diagram for In-band Relay

3. System Parameters/Characteristics determining Relay impact

The system throughput gains due to relays may be improved by tweaking several system parameters. Figure 2 shows that increases in any of the system parameters (blue →) can increase DL system throughput gain. Here it is assumed that relays are located in low geometry regions for noise limited networks.

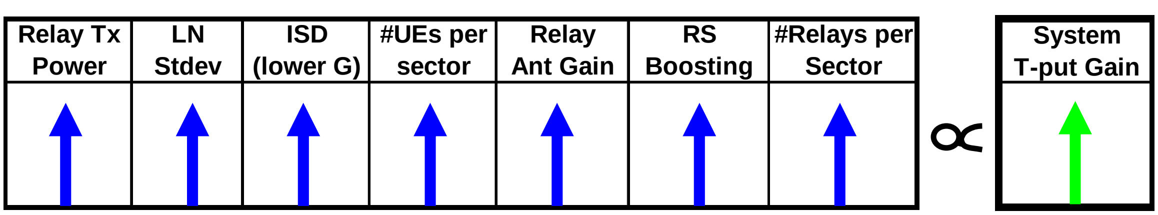

Figure 2 – Correlation of System Parameters and DL System Performance Gain (due to Relays)

Furthermore, the increase in system T-put gain is highly correlated to average #UEs served per relay that itself depends on the system parameters shown in Figure 3.

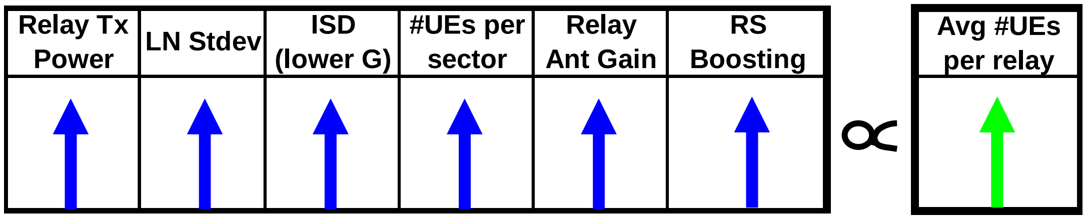

Figure 3 – Larger values of the above System parameters improve Average #UEs per relay

Figure 4 and Table 2 show quantitatively the simulated benefit of relays for different system parameter/characteristic values indicated in Figure 2 (see *Annex B* for system simulation assumptions). Performance gains drop by about 50% due to overhead from 1) the division of macro eNB downlink resources between the UEs it serves (UE1) and the UEs served by the relay (UE2) and to a much lesser extent from 2) the TDD aspect of in-band relays. See *Annex A* for more analysis.

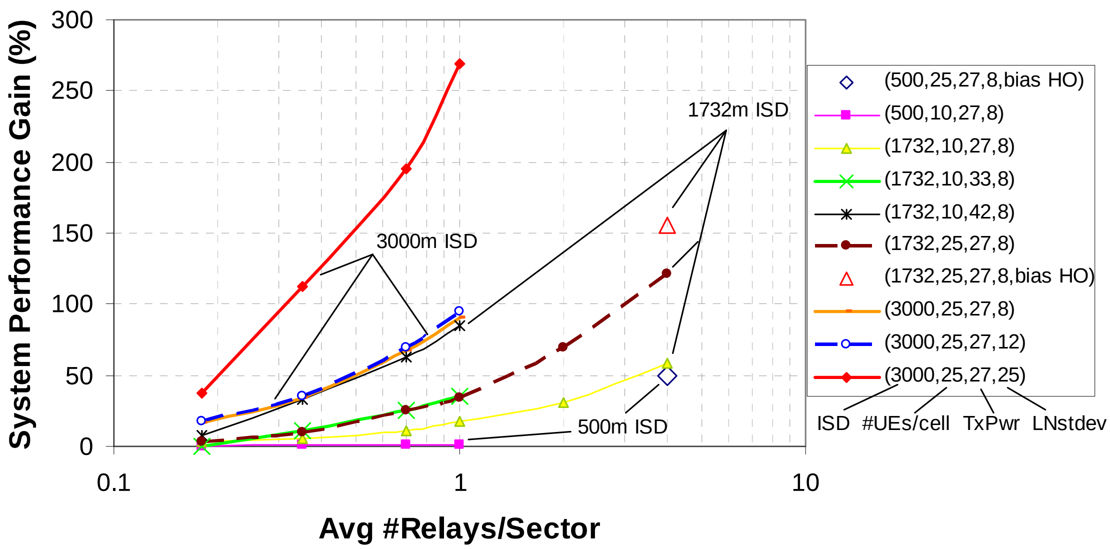

Figure 4 – DL System Performance Gain from Relays for different System Parameter Values

Note: *System Performance Gain = 5%-ile user t-put gain + sector t-put gain;*

4. Location of Relays

Another important consideration is the distribution of Relay locations in the network. For interference limited networks (such as deployment scenario case 1) the relay locations can be uniform random while achieving significant system performance gain. However, for noise limited networks more system performance gain is achieved if the relays are located in low geometry regions. In fact, the gains improve by dropping the relays in the worst geometry locations rather than dropping the RN in a randomly selected location from a set of low-geometry locations (e.g. locations with C/I <= -5 dB) – see [1]. However, the relay location can be relaxed as the number of relays per sector and/or the relay coverage increases.

5. Time Multiplexing of Relay and eNB DL transmissions (muting)

In [2] it was shown that significant performance gain can be derived by muting relay DL transmissions while eNB DL transmissions occur and muting eNB DL transmissions while relay DL transmissions occur. The technique was referred to as cooperative silencing. Also with this technique the percentage of UEs attached to relays was biased to be 60% in each cell where each cell had 4 relays. From analysis and simulations it appears that the main performance contributor is due to biasing a larger percentage of UEs to be attached to relays and not so much the muting aspect as shown in Table 1. The base station can determine whether a UE is served by it or a relay based on load balancing. **Biasing UEs so they are served by relays instead of the donor cell can be accomplished by properly setting reselection offsets.**

Table 1 – System Performance gain from muting and %UEs connected to Relay

	5%-ile user t-put gain	50%-ile user t-put gain	mean sector t-put gain
Case 1 (R1-090370), muting, Relay UEs: 60%	19%	29%	33%
Case 1, non-muting (simulat.), Relay UEs: 23%	22%	38%	29%
Case 1, non-muting (analytic), Relay UEs: 60%	273%	156%	109%
Case 1, muting (analytic), Relay UEs: 60%	16%	56%	30%
Case 3, non-muting (simulat.), Relay UEs: 35%	28%	72%	122%
Case 3, non-muting (simulat.), Relay UEs: 10%	9%	29%	110%
Case 3, muting (analytic), Relay UEs: 20%	-29%	3%	32%

* uniform random relay location in each sector for case 1; 4-relays/sector; relay Tx Power=27dBm;

6. Conclusion

Relay location strategy significantly impacts expected relay induced system performance gains.

- Relay location becomes less important as #relays per cell increases.
- Interference limited networks can tolerate uniform random relay locations
- Noise limited networks require relay locations in low geometry regions.

Certain system parameters/characteristics greatly determine relay based system performance gain but also have other effects/constraints such as -

- Increase relay size and cost (e.g. higher power or antenna gain)
- High system cost (e.g. >1 relay per sector)
- Primarily determined by deployment physics and hence not easily controllable
    - (e.g. higher ISD with more low G regions or large LN shadowing stdev)
- Low cost and simple to apply (e.g. RS boosting / bias HO attachment)

In general increasing relay coverage (i.e. more UEs/Relay) increases system performance gain.

- RS boosting or biasing HO thresholds are simple low cost way to inc. #UEs/relay.

Overhead from sharing eNB DL resources between UE1 and Relays (UE2) reduces relay induced system performance gain by ~ 50%. (TDD aspect of in-band relay degrades performance to a lesser extent).

7. References

[1] R1-090801, "Uniform Random UE Locations for Relays and Macro Cells," Motorola, RAN1#56, Athens, Greece, February 2009.

[2] R1-090370, "Initial Evaluation of Relay Performance," Qualcomm, RAN1#55bis, Ljubljana, Slovenia, January 2009.

[3] R1-090242, "Effect of Relaying on Coverage," Nokia, RAN1#55bis, Ljubljana, Slovenia, January 2009.

[4] R1-090333, "In-band relay impact on System Performance for best effort traffic," Motorola, RAN1#55bis, Ljubljana, Slovenia, January 2009.

[5] R1-090073, "A system simulation study of downlink L2 relay network," ZTE, RAN1#55bis, Ljubljana, Slovenia, January 2009.

[6] R1-090107, "Performance Evaluation of Layer 3 relays," Samsung, RAN1#55bis, Ljubljana, Slovenia, January 2009.
[7] R1-090134, "Performance Evaluation of Layer 1 relays," Huawei, RAN1#55bis, Ljubljana, Slovenia, January 2009.
[8] R1-090243, "Cell Edge Performance for Amplify and Forward vs. Decode and Forward Relays," Nokia, RAN1#55bis, Ljubljana, Slovenia, January 2009.
[9] R1-090392, "Impact of repeater deployment on LTE-Advanced performance," Mitsubishi Electric, RAN1#55bis, Ljubljana, Slovenia, January 2009.

Table 2 – DL System Performance Gain from Relays for different System Parameter Values

(ISD(m), UEs/sector, Relay TxPwr (dBm), LN Stdev (dB))	Performance Gain vs. Average #Relays/Sector				
	0.18	**0.35**	**0.70**	**1**	**2**
500, 10, 27, 8	0.4%	1.0%	0.9%	0.8%	
1732, 10, 27, 8	3%	6%	11%	18%	31%
1732, 10, 33, 8	-0.5%	11%	25%	35%	
1732, 10, 42, 8	8%	33%	63%	85%	
1732, 25, 27, 8	3%	10%	25%	34%	70%
3000, 25, 27, 8	16%	34%	67%	90%	
3000, 25, 27, 12	18%	35%	70%	95%	
3000, 25, 27, 25	37%	112%	195%	269%	

Note: *System Performance Gain = 5%-ile user t-put gain + sector t-put gain;*

Annex A
System Performance Impact from Relay Overhead

No relay case:

Suppose each eNB serves M UEs, and the average sector throughput is R.

Out-band relay case:

Suppose N out-band relays are dropped in a sector, and on average each relay serves λ UEs (i.e., the number of UEs served by relays forms a Poisson distribution with mean λ).

It was observed from system simulation results that typically a relay delivers an average throughput approximately equal to half of an eNB's average throughput. Therefore, each relay has throughput of $R/2$.

As the Poisson distribution has mean λ, there are $N\lambda$ UEs served by relays, and the fraction of relays in use (i.e., serving at least one UE) is $(1-e^{-\lambda})$. So totally $(1-e^{-\lambda})N$ relays are in use, and they have total throughput of $\frac{1-e^{-\lambda}}{2}NR$.

Now the eNB serves only $(M - N\lambda)$ UEs, which may slightly improve the eNB's throughput. Assume the improved throughput is $\frac{M}{M - N\lambda}R$.

Thus, with N out-band relays, the average sector throughput is estimated to be

$$\left(\frac{1-e^{-\lambda}}{2}N + \frac{M}{M-N\lambda}\right)R, \tag{1}$$

and the out-band relay throughput gain is

$$g_{out} = \frac{1-e^{-\lambda}}{2}N + \frac{1}{\frac{M}{N\lambda}-1}. \tag{2}$$

In-band relay case:

It is assumed that the eNB→RN link is twice as efficient as the eNB→UE1 link. Therefore, to support relay throughput $\frac{1-e^{-\lambda}}{2}NR$, the eNB→UE1 throughput is reduced by $\frac{1}{2}\frac{1-e^{-\lambda}}{2}NR$.

Thus, with N in-band relays, the average sector throughput is estimated to be

$$\left(\frac{1-e^{-\lambda}}{2}N - \frac{1}{2}\frac{1-e^{-\lambda}}{2}N + \frac{M}{M-N\lambda}\right)R, \tag{3}$$

and the in-band relay throughput gain is

$$g_{in} = \frac{1-e^{-\lambda}}{4}N + \frac{1}{\frac{M}{N\lambda}-1}. \tag{4}$$

Further approximation:

If $N\lambda$, the number of UEs served by relays is small compared to M, the number of UEs in a cell, then the out-band gain and in-band gain can be approximated by

$$g_{out} \approx \frac{1-e^{-\lambda}}{2}N \tag{5}$$

And

$$g_{in} \approx \frac{1-e^{-\lambda}}{4}N. \tag{6}$$

That is, the in-band gain is approximately half of the out-band gain.

It may also be concluded that the out-band gain should be close to $\frac{N\lambda}{2}$ and the in-band gain should be close to $\frac{N\lambda}{4}$. Therefore, increasing the number of relays and the mean number of UEs served by relays can increase the throughput gain when relays are used.

Annex B: simulation assumptions

Table 3 - Simulation Assumptions

Parameter	Assumption/Value
Cellular layout	Hexagonal grid, 19 macro eNB cell sites, 3 cells per site, wrapped-around
Relay layout	1 cell per site, not wrapped-around
Inter-site distance (ISD)	1732 m
Distance-dependent path loss for macro eNBs	$L = 128.1 + 37.6\log_{10}(R)$, R in kilometers
Distance-dependent path loss for relays	$L = 140.7 + 36.7\log_{10}(R)$, R in kilometers
Lognormal Shadowing	As modeled in UMTS 30.03, B 1.4.1.4
Shadowing standard deviation: macro to UE	8 dB
Shadowing standard deviation: relay to UE	8 dB
Correlation distance of Shadowing	50 m
Shadowing correlation: Between sites	0.5
Shadowing correlation: Between cells per site	1.0
Penetration loss from macro to UE	20 dB
Penetration loss from relay to UE	20 dB
Carrier frequency	2 GHz
Bandwidth	5 MHz
Subcarrier spacing	15 kHz
Resource block size	180 kHz (12 subcarriers)
Subframe duration	1.0 ms
Number of OFDM symbols per subframe	14 (11 used for data, 2 for control ($n=2$), 1 for RS overhead)
Channel model	Typical Urban (TU) used for PDSCH
UE deployment	570 UEs over 57 cells (uniform random spatial distribution over the network)
Minimum distance between UE and BS	35 m
Minimum distance between relays	350 m
Frequency reuse factor	1
Hybrid ARQ scheme	IR , Chase combining (asynchronous) (2/3<MCS<4.8), 16 levels
Hybrid ARQ round trip delay	8 subframes (ms)
Thermal noise density	-174 dBm/Hz
Antenna pattern for macro eNBs (horizontal)	$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right]$ θ_{3dB} = 70 degrees, A_m = 25 dB (70 degree horizontal beamwidth)
Antenna pattern for relays (horizontal)	0dB for all directions
Antenna pattern for macro eNBs and relays (vertical)	$A(\theta) = -\min\left[12\left(\frac{\theta - \theta_{etilt}}{\theta_{3dB}}\right)^2, SLA_v\right]$ θ_{3dB} = 20 degrees, SLAv = 20 dB
Total macro BS TX power	20 Watts, 43 dBm
Total relay TX power	0.5 Watt, 27 dBm
BS and relay antenna gain (incl. cable loss)	14 dBi and 5 dBi respectively
BS and relay transmitter	2 antennas
UE speed	3 km/h
UE receiver	2 antennas
UE antenna gain	0 dBi
UE noise figure	9 dB
CQI feedback delay	2 ms
CQI subband size	180 kHz (12 subcarriers)
CQI quantization	5 bits per value/subband
CQI feedback cycle	2 ms
CQI Error	1dB for low SINR and 0.5 for high SINR
Traffic type	Full buffer
Scheduler	Time and frequency selective Proportional Fair scheduler
Control channel model	Ideal
UE Channel Estimation	Non Ideal
Simulation drops	15