On the Throughput Enhancement of Fixed Relay Concept in Manhattan-like Urban Environments

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Outline

- Introduction
- Manhattan Cellular Environment
- Pathloss Models
- Interference Scenario
- Performance Results
- Wired Relay
- Summary

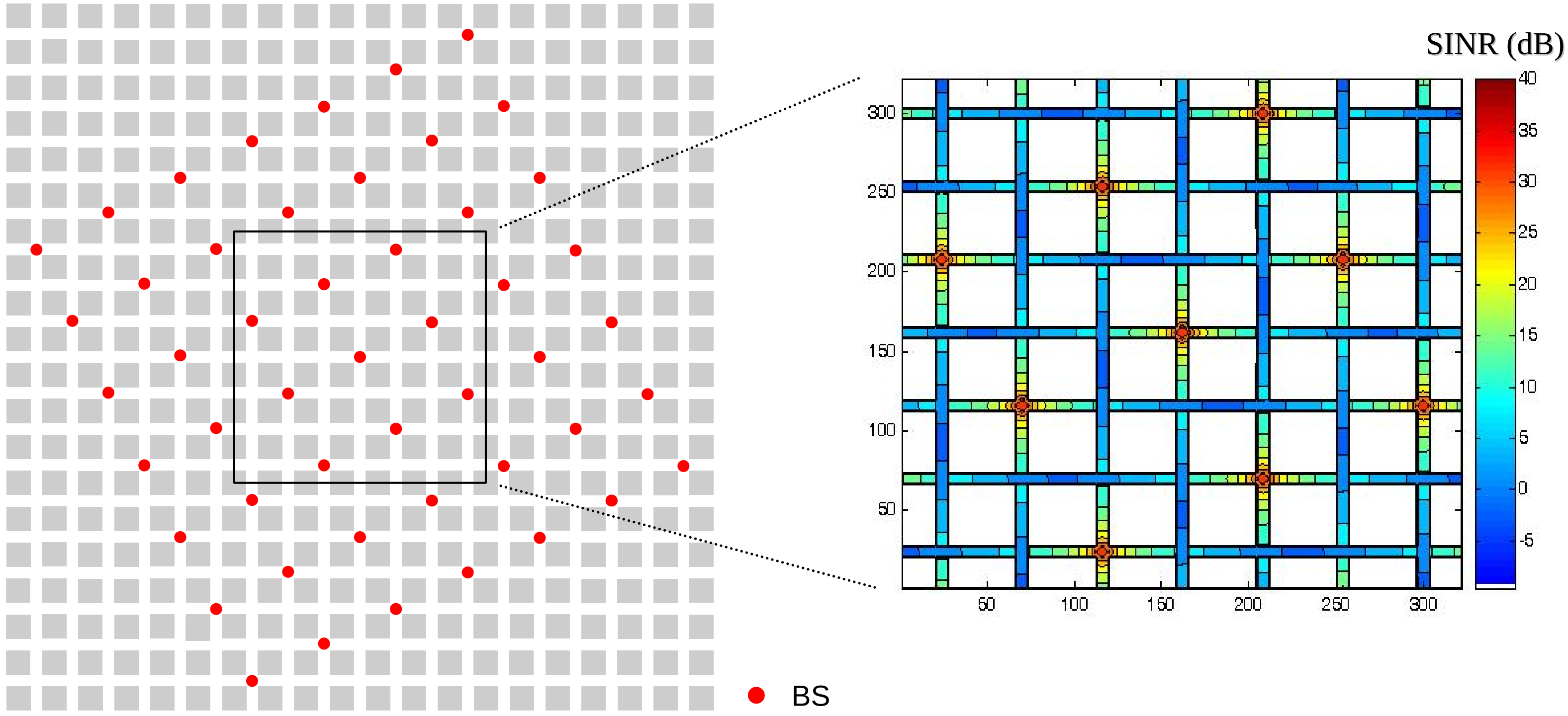
Introduction

In this contribution, we show …

- Throughput improvement that can be achieved by fixed relay
  - Coverage advantage is obvious and previously studied
  - Comparison: Single-hop vs. Repeater vs. Multi-hop
  - In Manhattan-like urban environment
  - For best-effort type service in down- and up-links
- Utilization of wired relay
  - Employing both wired and wireless relays can provide a significant flexibility in deployment and operation of wireless networks

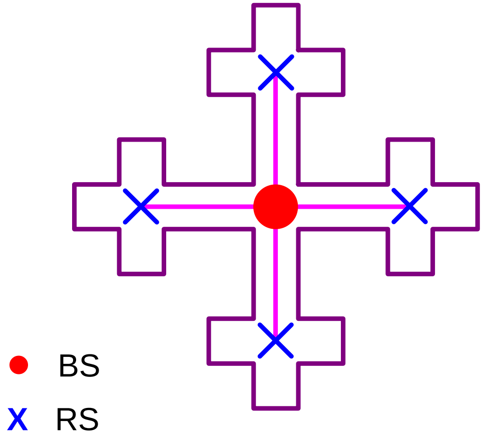
Manhattan Urban Environment

- Deployment model
  - Total 49 BS's, Block size: 200 m, Road width: 30 m
  - Frequency reuse = 1

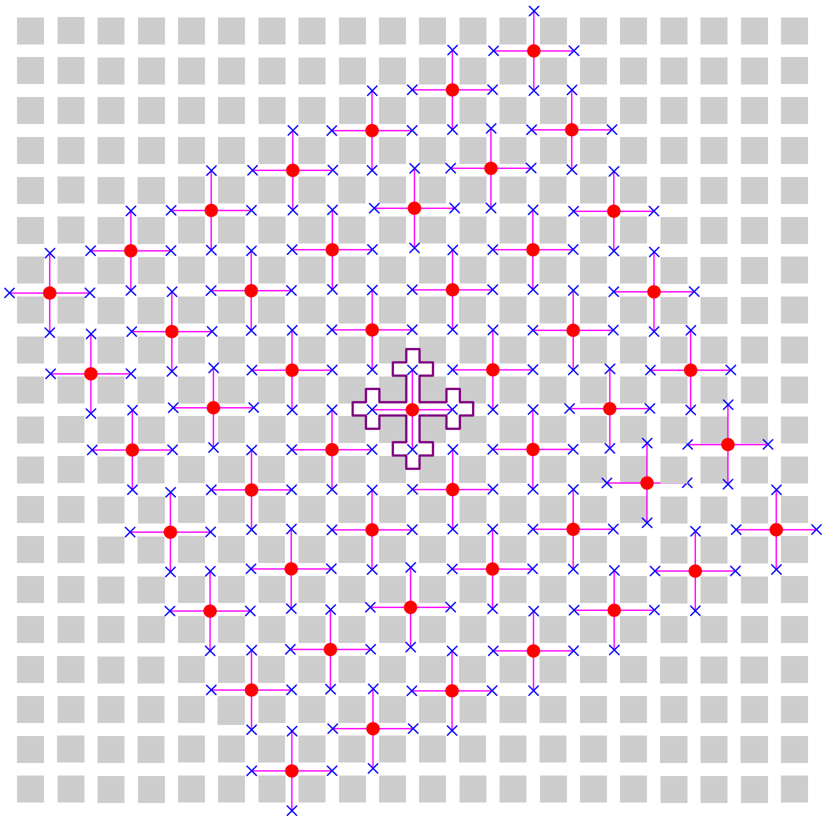


RS Deployment Model

- Number of RS's per BS = 4
- Frequency reuse among relays = 1 or 4



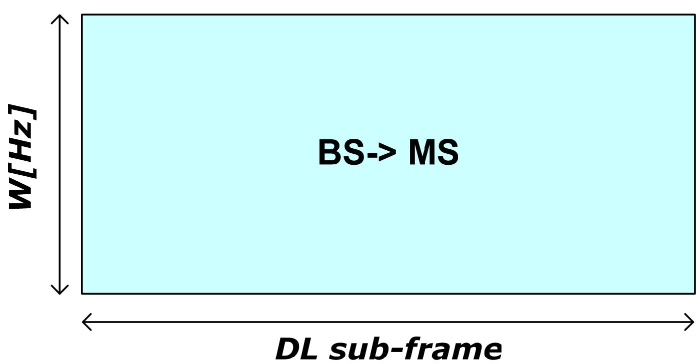
BS deployment with RS's



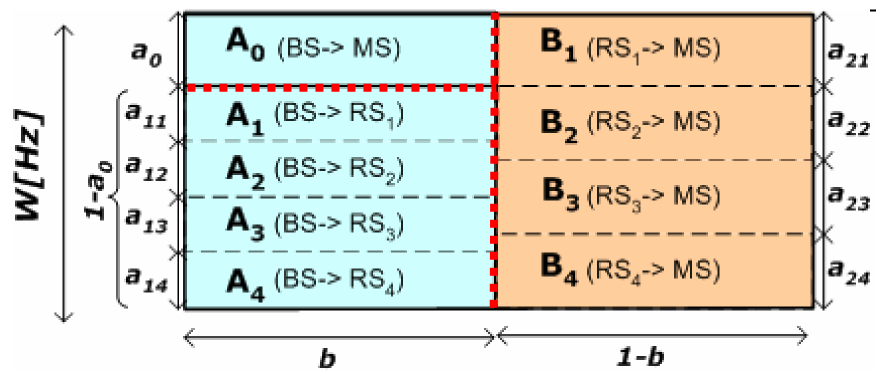
Statistical data from the center cell are collected.

Frame Structure Model

- TDD OFDMA
- Dedicated RS: no data source/sink (infrastructure type), 2-hop relay
- Assumed a homogeneous network with uniform traffic density



[Single-hop & Repeater]



[Relay]

where,

W : Total bandwidth

a_0 : Ratio of freq. bandwidth allocated to BS sub-cell

a_{1i} : Ratio of freq. bandwidth allocated to relaying transmission (BS-RS links)

a_{2i} : Ratio of freq. bandwidth allocated to RSi sub-cell

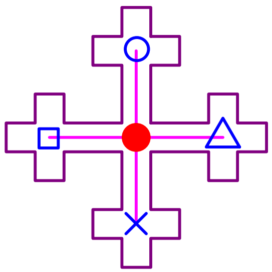
b : Ratio of frame time assigned to BS transmission

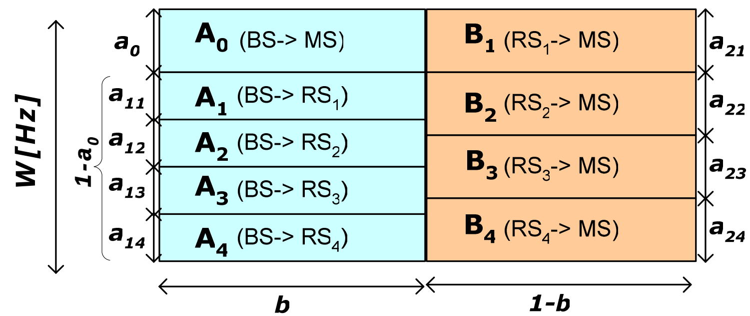
γ_{relay}^{BS} : Received SINR from BS sub-cell

$\gamma_{relay}^{RS_i}$: Received SINR from RS sub-cell

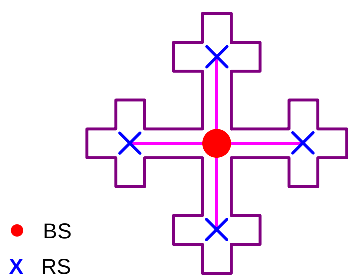
Frequency Reuse among Relays

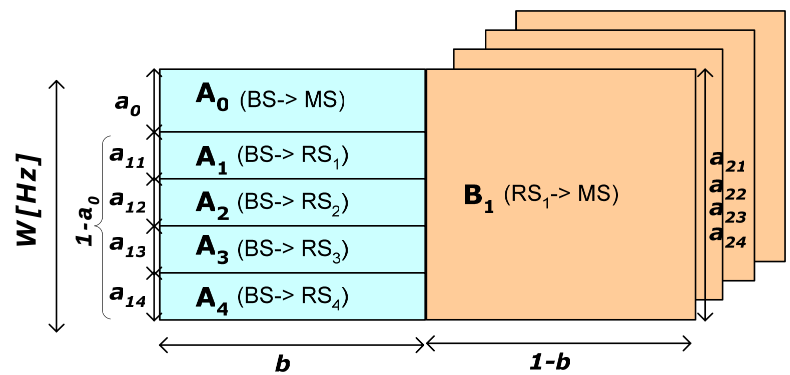
- Frequency reuse factor among RS-MS links (K_r)
  - K_r = 4: Different channel for each RS





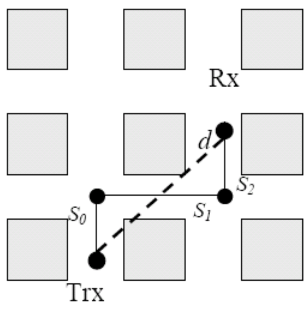
  - K_r = 1: Same channel for all RS's





Pathloss Model

- 3GPP Model [1]
  - Min(manhattan pathloss, macro pathloss)
  - Manhattan pathloss:

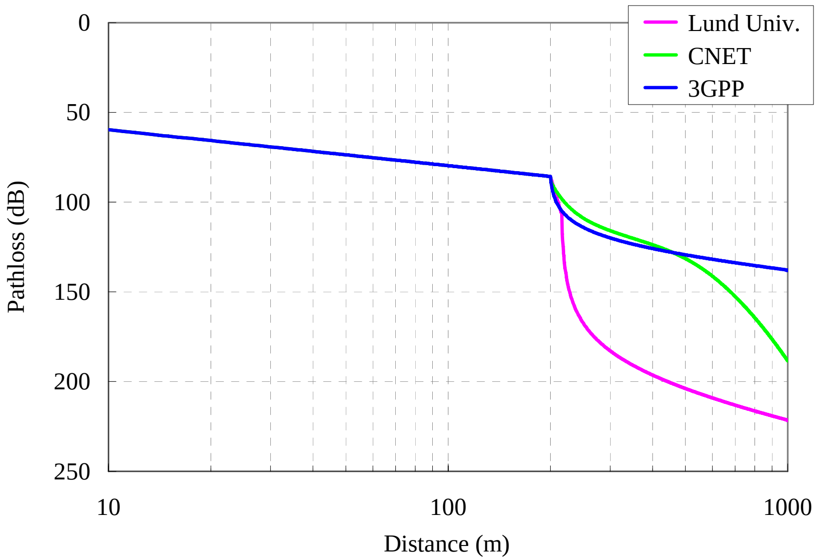


$$L = 20 \cdot \log_{10}\left(\frac{4\pi d_n}{\lambda} \cdot D\left(\sum_{j=1}^{n} s_{j-1}\right)\right) \qquad D(x) = \begin{cases} x / x_{br}, & x > x_{br} \\ 1, & x \le x_{br} \end{cases}$$

  - Macro pathloss (COST Walfish-Ikegami Model):

$$L = 24 + 45 \cdot \log_{10}(d + 20)$$

- Lund Univ. Model [2]
- CNET Model [3]

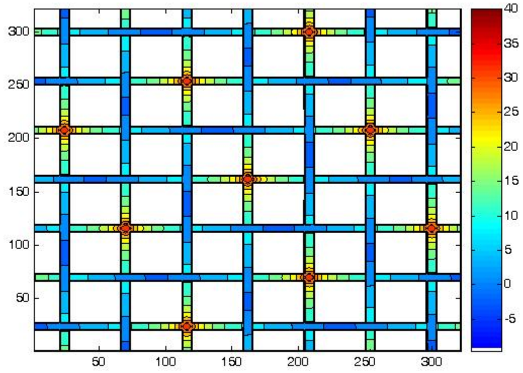


[1] 3GPP TR 101 112, UMTS 30.03, ver. 3.2.0, 1998
[2] H. Borjeson et al., "Outdoor microcell measurement at 1700MHz," in Proc. IEEE VTC'92
[3] W. Joe, "Micro-cellular modeling when base station antenna is below roof tops," in Proc. IEEE VTC'04

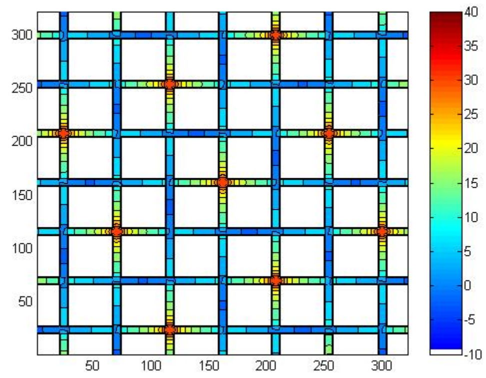
Pathloss Model (cont'd)

- SINR vs. Pathloss Model
  - Geographical distribution

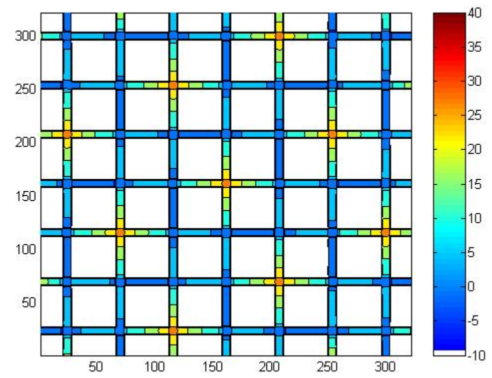
3GPP



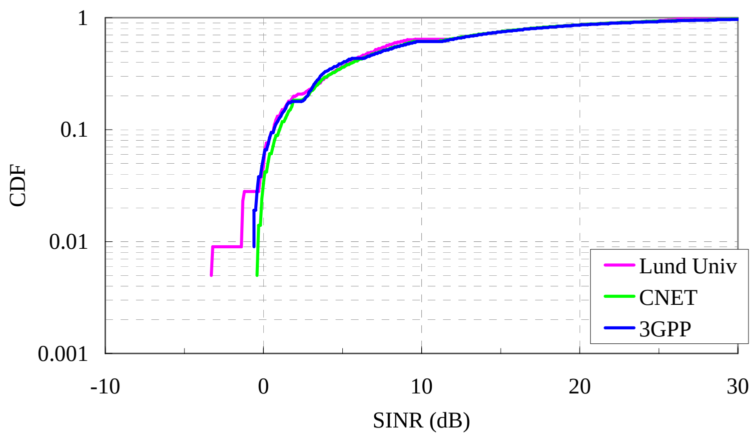
CNET



Lund Univ.



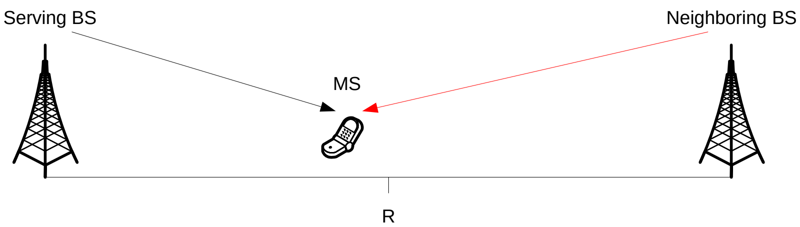
  - CDF



SINR is not so much affected by pathloss model

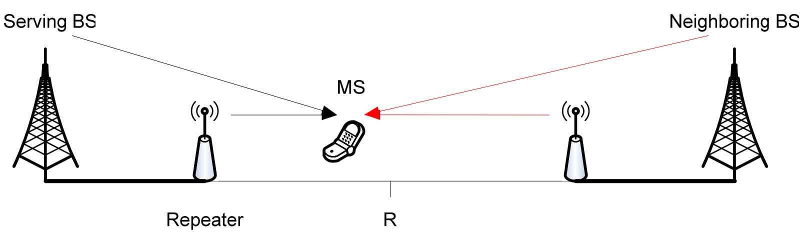
DL Interference Modeling

- Single-hop system



$$\gamma_{BS} = \frac{P_p \cdot G_{BS} \cdot L_{0,m}}{\sum_{i=1}^{B} P_p \cdot G_{BS} \cdot L_{i,m} + N \cdot NF_{MS}}$$

- Repeater System (e.g. optical repeater)



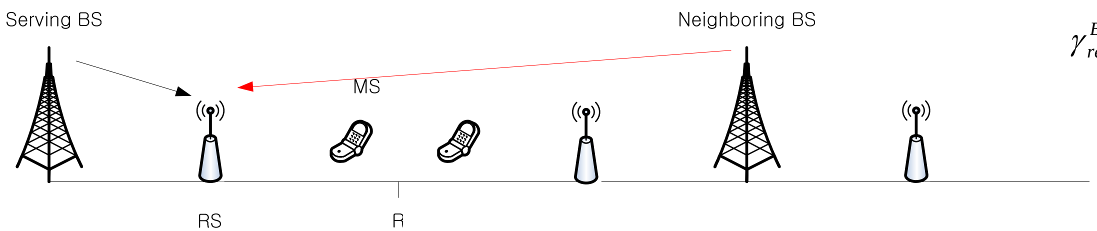
$$\gamma_{BS} = \frac{P_p \cdot G_{BS} \cdot L_{0,m} + \sum_{j=0}^{R'} P_r \cdot G_R \cdot L_{j,m}^{(r)}}{\sum_{i=1}^{B} P_p \cdot G_{BS} \cdot L_{i,m} + \sum_{j=0}^{R-R'} P_r \cdot G_R \cdot L_{j,m}^{(r)} + N \cdot NF_{MS}}$$

P_{BS_i} : Transmission power of BS i (if i=0:serving BS)
$P_{RS_i}^{j}$: Transmission power of RS j in i-th cell (if j=0:dedicated RS)
G : Antenna gain
$L_{a,b}$: Transmission loss between node a and b

M_{BS} : Total number of other cell BSs
M_{RS_i} : Number of RSs in i-th cell (if i=0:serving BS)
T : Index of other cell RS having same index with serving RS in cell 0
N : Thermal noise power
NF_{MS} : The noise figure of MS

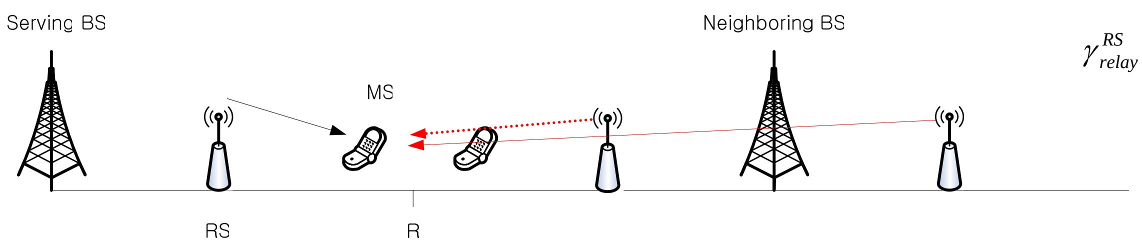
DL Interference Modeling (cont'd)

- Relay System
  - 3 different links: BS-MS link, BS-RS link, RS-MS link
  - BS-RS link



$$\gamma_{relay}^{BS} = \frac{P_{0,0,p}\cdot G_{0,0}\cdot L_{0,0,j}}{\sum_{i=1}^{B} P_{i,0,m}\cdot G_{i,0}\cdot L_{i,0,j} + N\cdot NF_{MS}}$$

  - RS-MS link



$$\gamma_{relay}^{RS} = \frac{P_{0,j,p}\cdot G_{0,j}\cdot L_{0,j,m}}{\sum_{i=1}^{B} P_{i,j,m}\cdot G_{i,j}\cdot L_{i,j,m} + N\cdot NF_{MS}}$$

System Model for Evaluation

- System Parameters
  - TX Power: BS 20 W, RS 10 W, MS 200 mW
  - Frequency: 2.3 GHz
  - Bandwidth: 10 MHz
  - Antenna type
    - BS & MS: Omni
    - RS: Directional antenna (15 dBi) for BS-RS link
      Omni for RS-MS link
  - Noise Figure: BS 5 dB, RS 5 dB, MS 9 dB
  - Thermal noise: -174 dBm/Hz
  - Full buffer model

System Model for Evaluation (cont'd)

- Antenna height and Break point

Model	Antenna Height (m)			Break Point (km)*		
	BS Ant	RS Ant	MS Ant	BS-MS link	RS-MS link	BS-RS link
Env_1	32	12.5	1.6	1.5	0.6	9.5
Env_2	12.5	5	1.6	0.6	0.25	1

- Short-term fading channel: PED-A 3km
  - Applied 2 different mapping functions (SINR → Data rate)

① Shannon capacity formula

② Based link-level analysis results (with MCS levels)

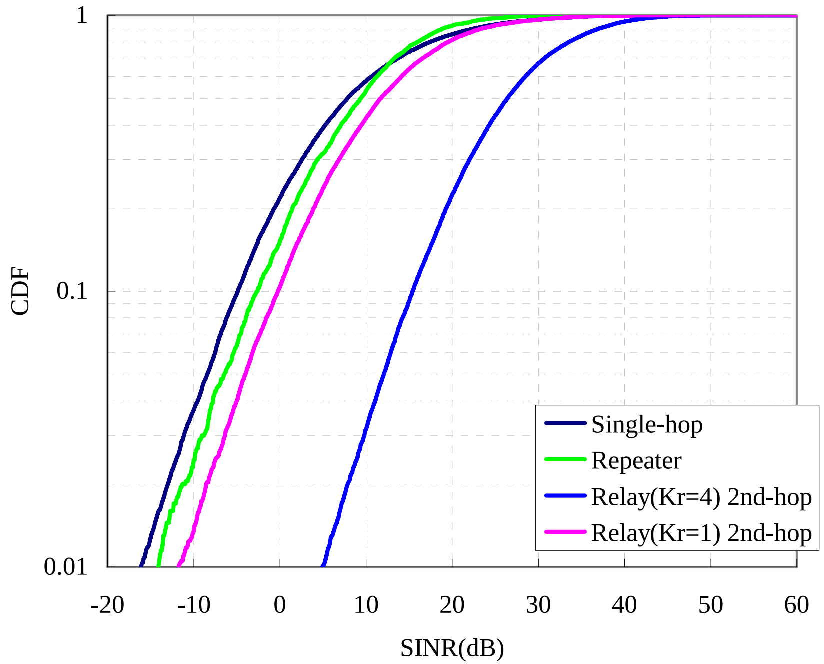
BS ↔ RS BS → MS RS → MS	Mod	QPSK					16QAM			64QAM	
	Code rate	1/12	1/6	1/3	1/2	2/3	1/2	2/3	5/8	2/3	5/6

BS ← MS RS ← MS	Mod	QPSK				16QAM		
	Code rate	1/12	1/6	1/3	1/2	1/3	1/2	2/3

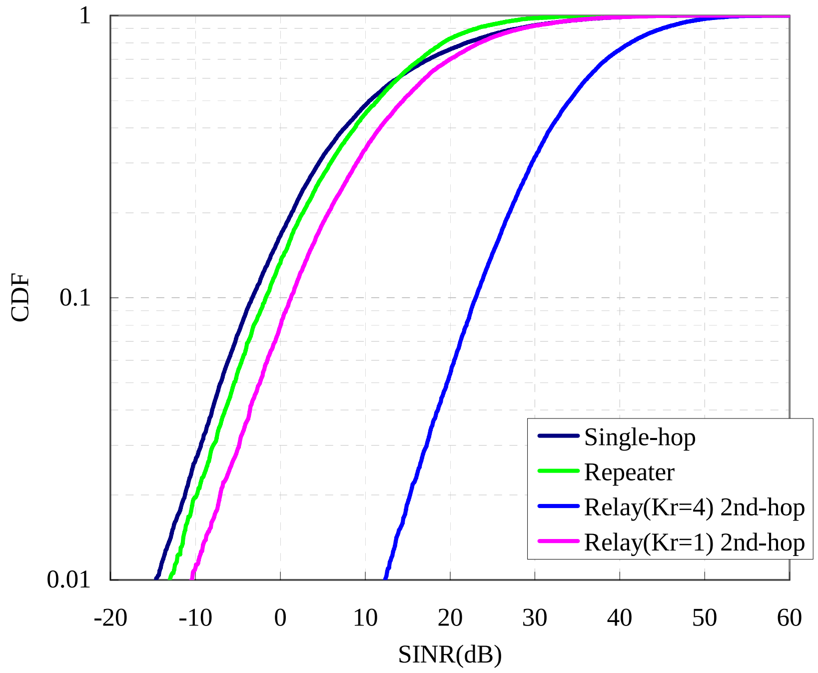
* Calculated by using the formula shown in the following paper; H. H. Xia et al., "Radio propagation characteristics for line of sight microcellular and personal communications," IEEE Trans. Antennas and Propagation, Oct. 1993.

SINR Distribution

DL in Env_1

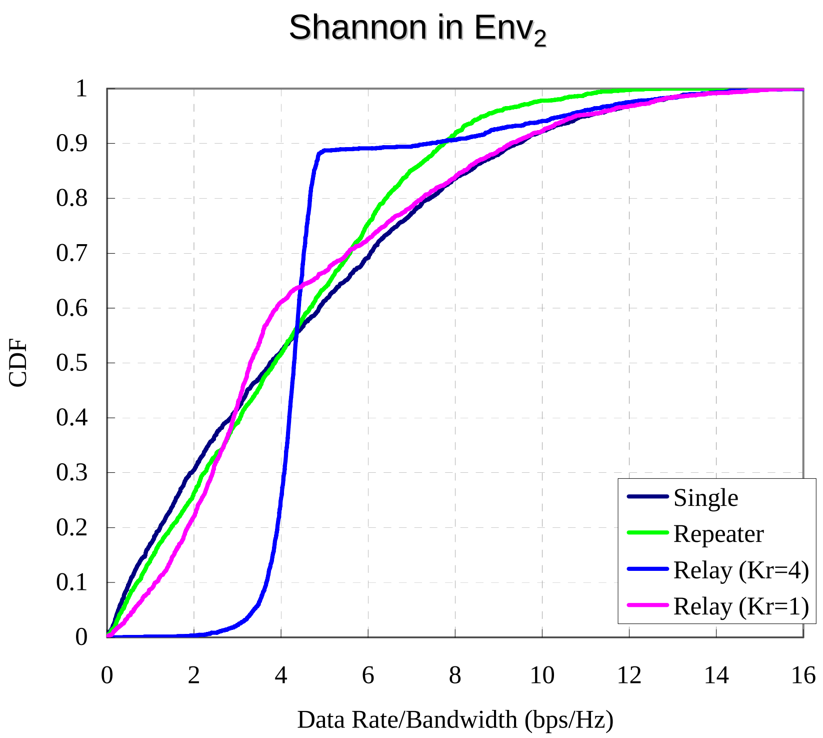


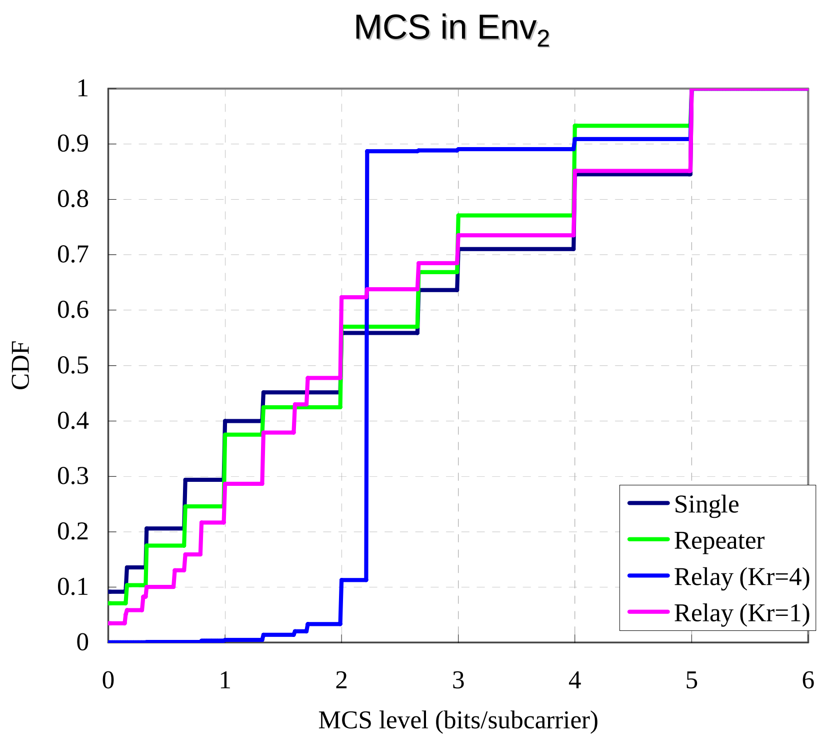
DL in Env_2



- SINR performance: Single hop system < Repeater system < Relay system
- As more frequency is reused (K_r ↓), SINR decreases but a gain from SDMA can be expected
- Higher SINR in Env_2, due to more link attenuation for interference

Effective User Data Rate (DL)



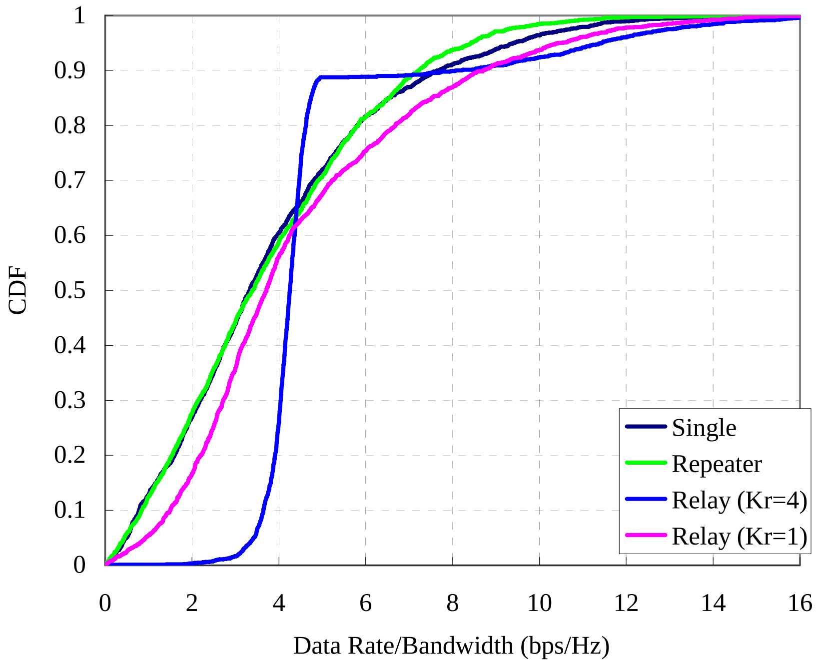


- Effective data rate/MCS level to a user (on single-hop path or 2-hop path)
  - Considered an additional channel resource for relay
  - $R = 1/(1/R_{1st} + 1/R_{2nd})$
    where $R_{N\text{ th}}$ is a data rate from Shannon formula or a MCS level for the Nth hop.

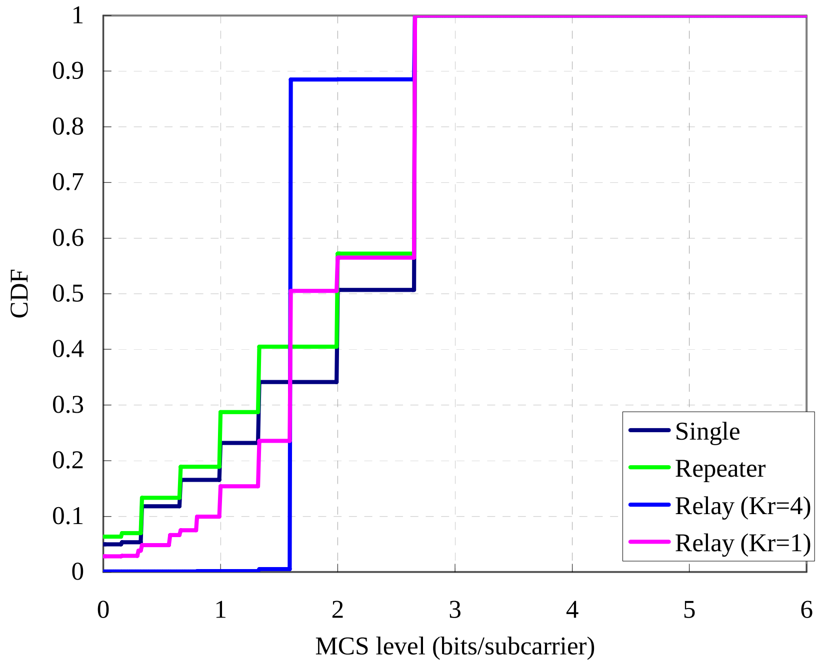
[Ref] J. Cho and Z. J. Haas, “On the throughput enhancement of the downstream channel in cellular radio networks through multi-hop relaying,” IEEE J-SAC, Sept. 2004.

Effective User Data Rate (UL)

Shannon in Env_2

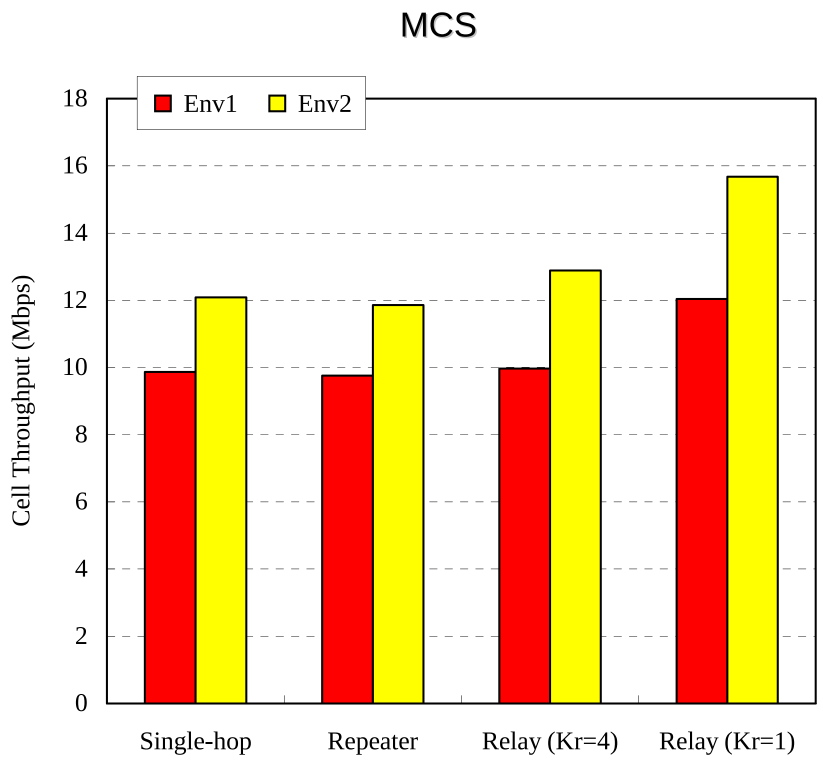


MCS in Env_2



- The effective data rate is affected by peak rate constraint of MS uplink (i.e. 16QAM, 2/3)
  - The biggest impact ⇒ Relay with $K_r = 4$

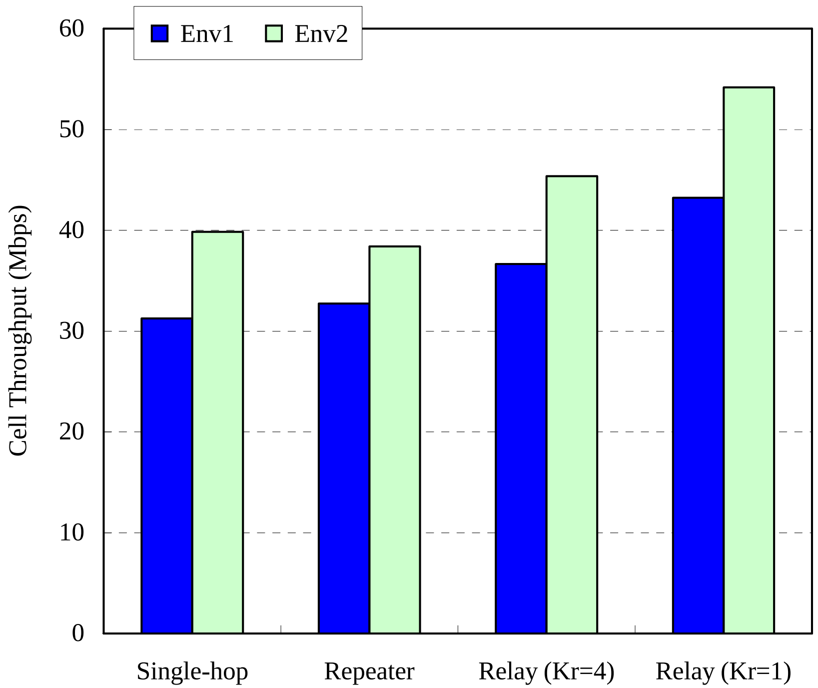
Cell Throughput (DL)



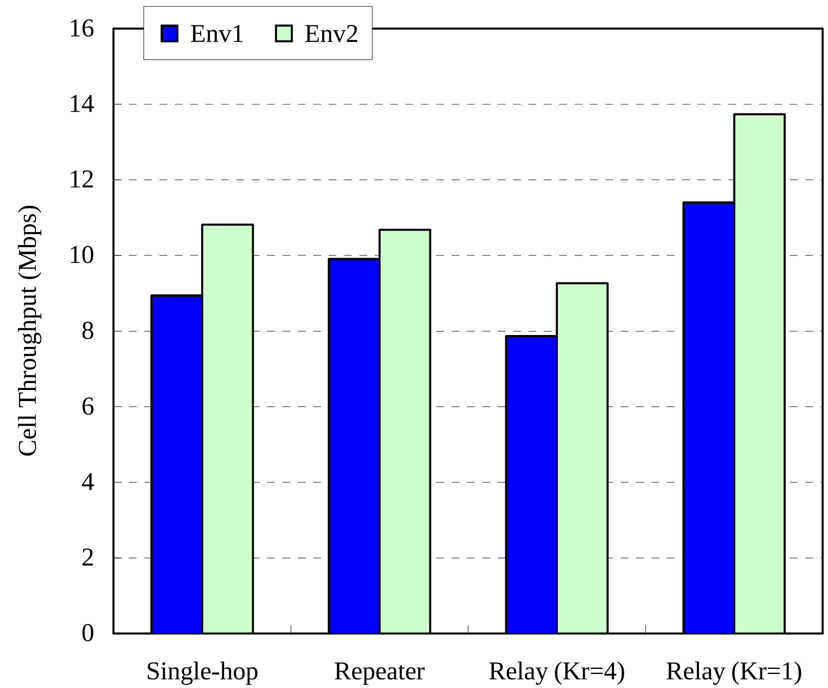
- Higher cell throughput in Env_2: Interference power is more attenuated.
- Throughput enhancement (Relay with K_r = 1 over Single-hop)
  - Shannon: 20% for Env_1, 22% for Env_2 MCS: 22% for Env_1, 30% for Env_2

Cell Throughput (UL)

Shannon



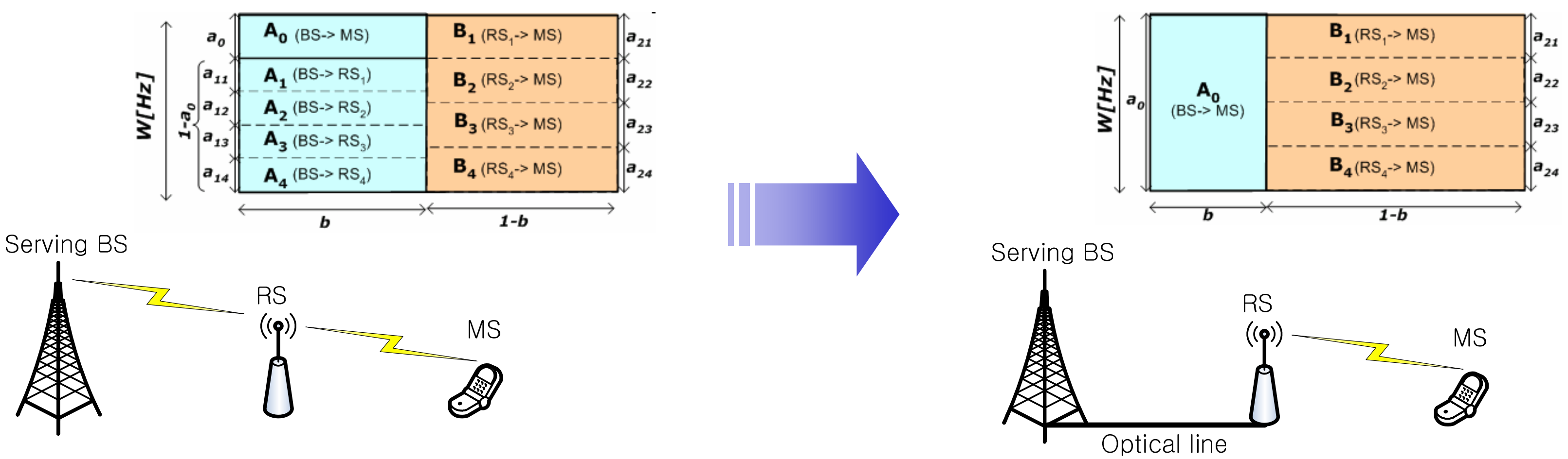
MCS



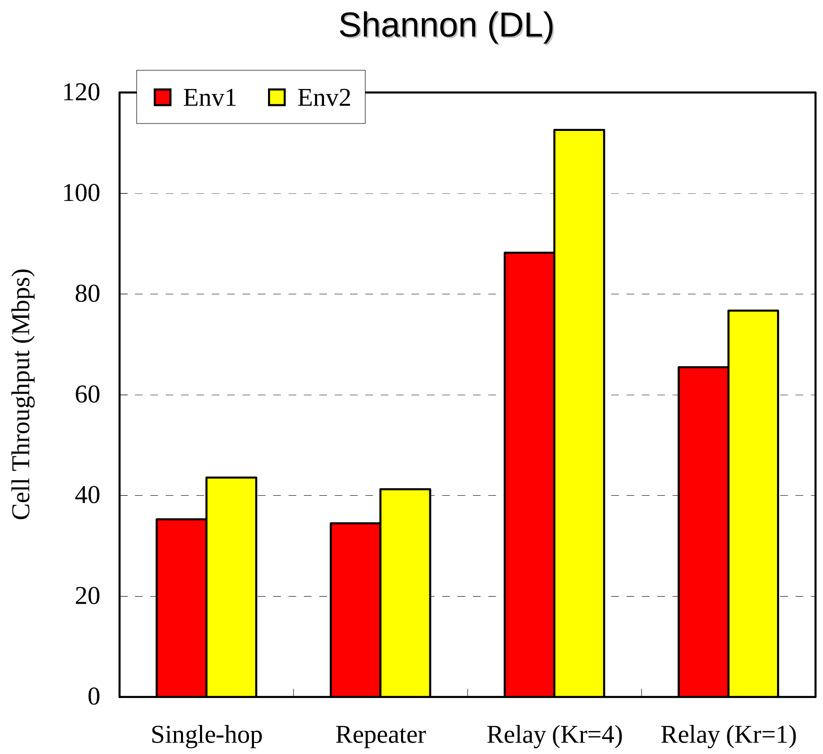
- Throughput enhancement (Relay with K_r = 1 over Single-hop)
  - Shannon: 38% for Env_1, 36% for Env_2 MCS: 27% for Env_1, 27% for Env_2
- The enhancement with MSC is less than with Shannon, due to lower peak rate constraint

Wired Relay System

- Penalty for employing relay
  - Additional radio resource for the BS-RS link
- At the initial deployment phase, connect BS and RS with wireless link
  - It allows *cheap* and *rapid* deployment
  - *Coverage* is important issue at the initial stage rather than capacity
- If high traffic flows into later on, then replace the wireless link with a wired line



Performance of Wired Relay



- Throughput enhancement (Relay with K_r = 4 over Single-hop)
  - Shannon: 150% for Env_1, 158% for Env_2 (so, about *2.5 times* throughput than single-hop)
- A quite large gain can be obtained by replacing wireless RS-BS link with wired line

Summary

- Throughput gain can be obtained through the use of 2-hop relay
  - Appropriate frequency reuse among RS's under a BS can significantly increase the system throughput
  - It can be confirmed that the fixed relay can provide capacity gain as well as coverage advantage

- Deployment strategy for wired and wireless fixed relays
  - At the initial deployment phase: Wireless relay
  - After deployment, if demanded: Replaced with wired relay for hot spot area