# Integrating Network Coding and Superposition Coding in Extended Two-way Relay Networks

**Li Chen**

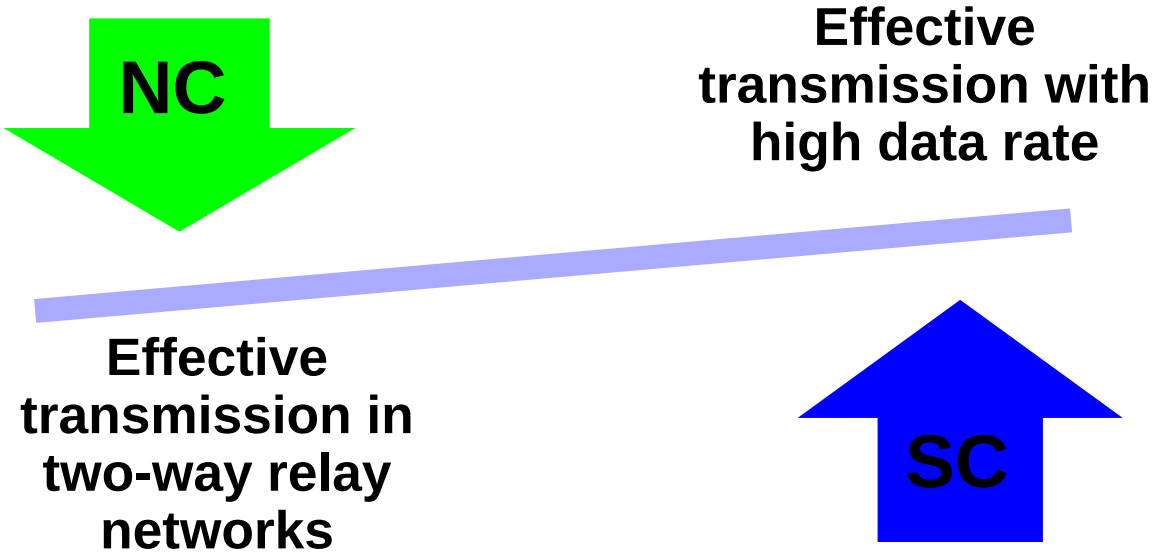
alibupt@gmail.com

# Outline

- Introduction
- System Model
  - System Model and Assumptions
  - Basic Idea
- Analysis of the Proposed Scheme
- Simulation and Analysis
  - Scenario with overhearing between neighboring nodes
  - Scenario without overhearing between neighboring nodes
- Conclusion
- References

# Introduction

- **This report introduces a novel information exchange scheme in extended two-way relay networks.**



# Introduction

**Basis**
- The principle of conventional information exchange scheme
- Some existed applications in wireless communication

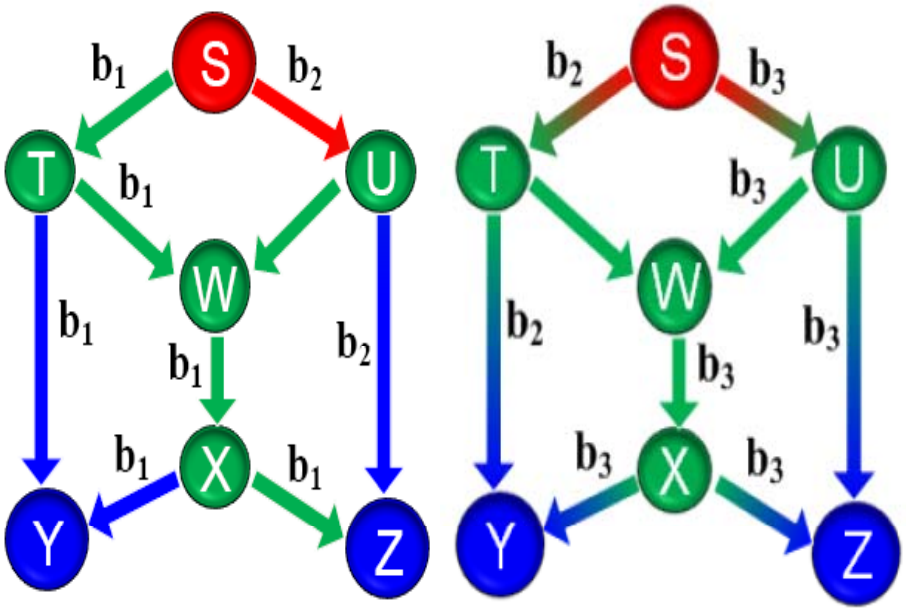
**Idea**
- A novel information exchange scheme among more than two nodes through relay node by integrating NC with SC

**Analysis**
- The achievable rate regions of the INSC scheme, conventional TD scheme and NC scheme
- The gains of the proposed scheme over conventional schemes

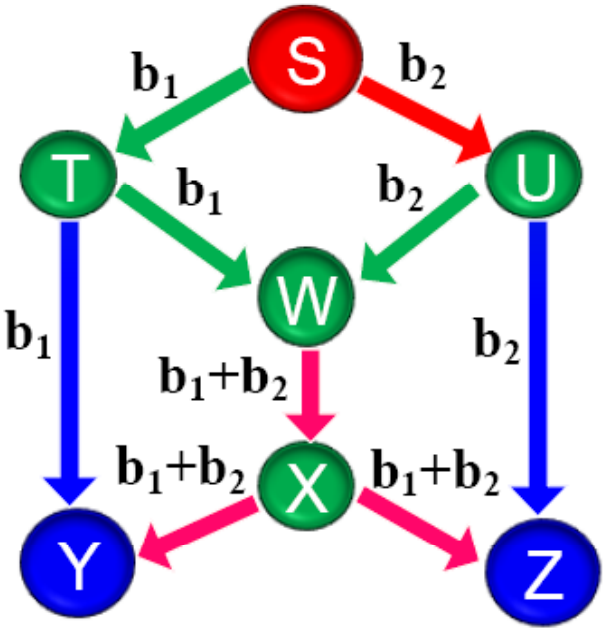
**Simulation**
- Scenario with overhearing between neighboring nodes
- Scenario without overhearing between neighboring nodes

# Application examples of NC

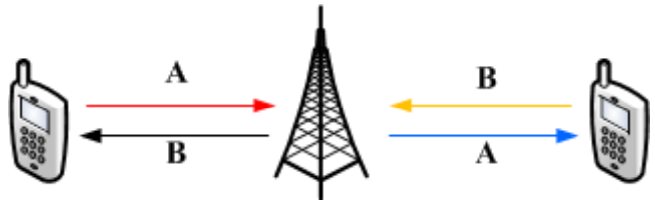
## Store and forward



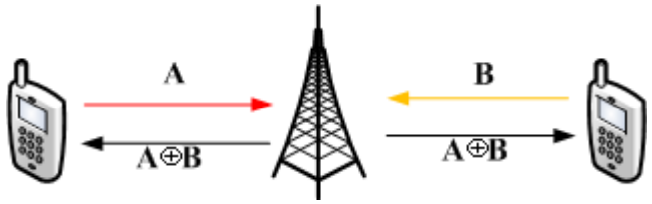

## NC-based




## Conventional Scheme




## NC-based Scheme



# Outline

- Introduction
- System Model
  - System Model and Assumptions
  - Basic Idea
- Analysis of the Proposed Scheme
- Simulation and Analysis
  - Scenario with overhearing between neighboring nodes
  - Scenario without overhearing between neighboring nodes
- Conclusion
- References

# System Model

**Fundamental Model**

- The networks where more than two nodes want to exchange their information though the only relay node (extended two-way relay networks).

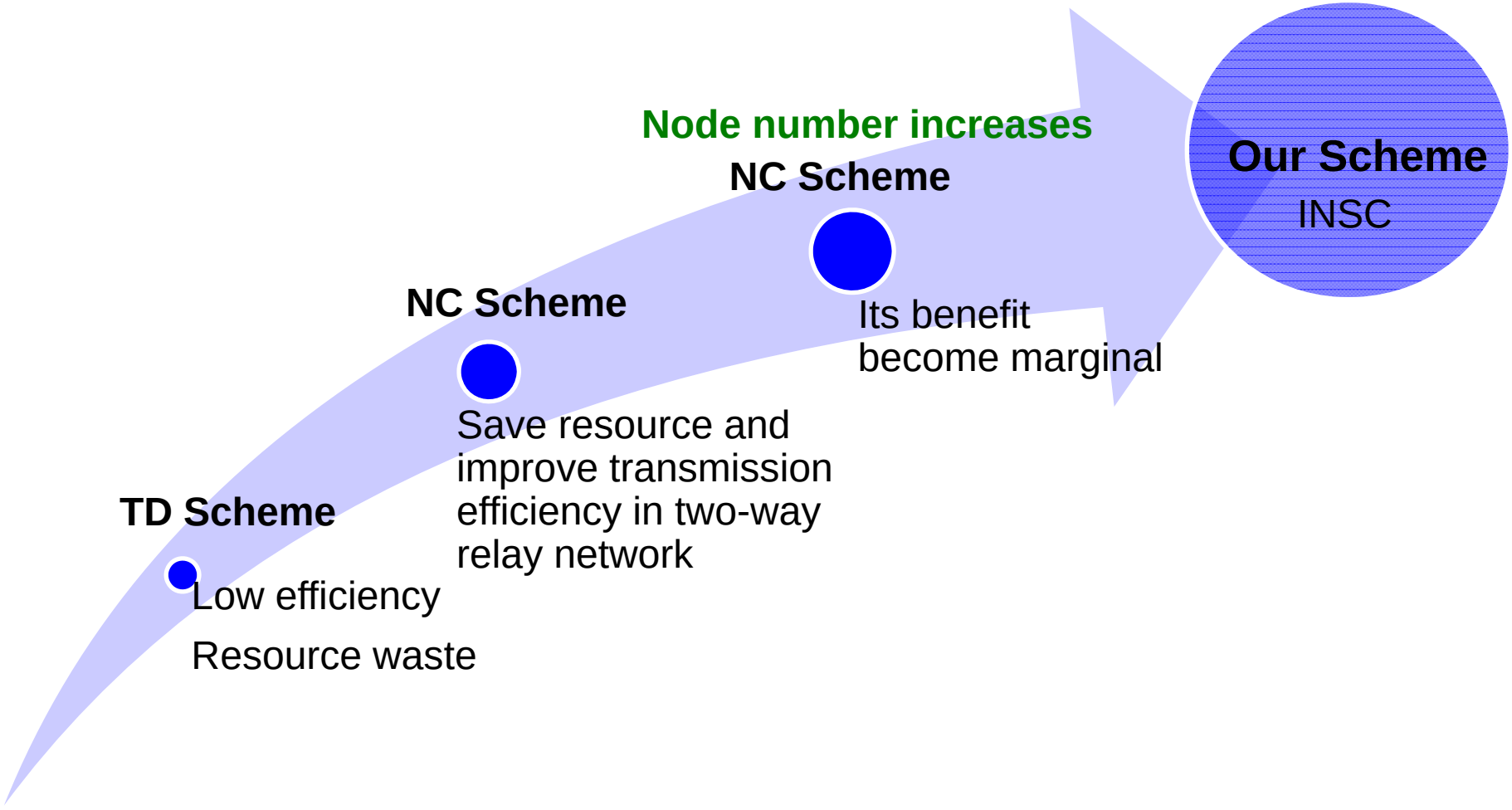
**Network Architecture**

- All nodes would like to exchange their packets with each other.
- There are many source nodes and one relay node.

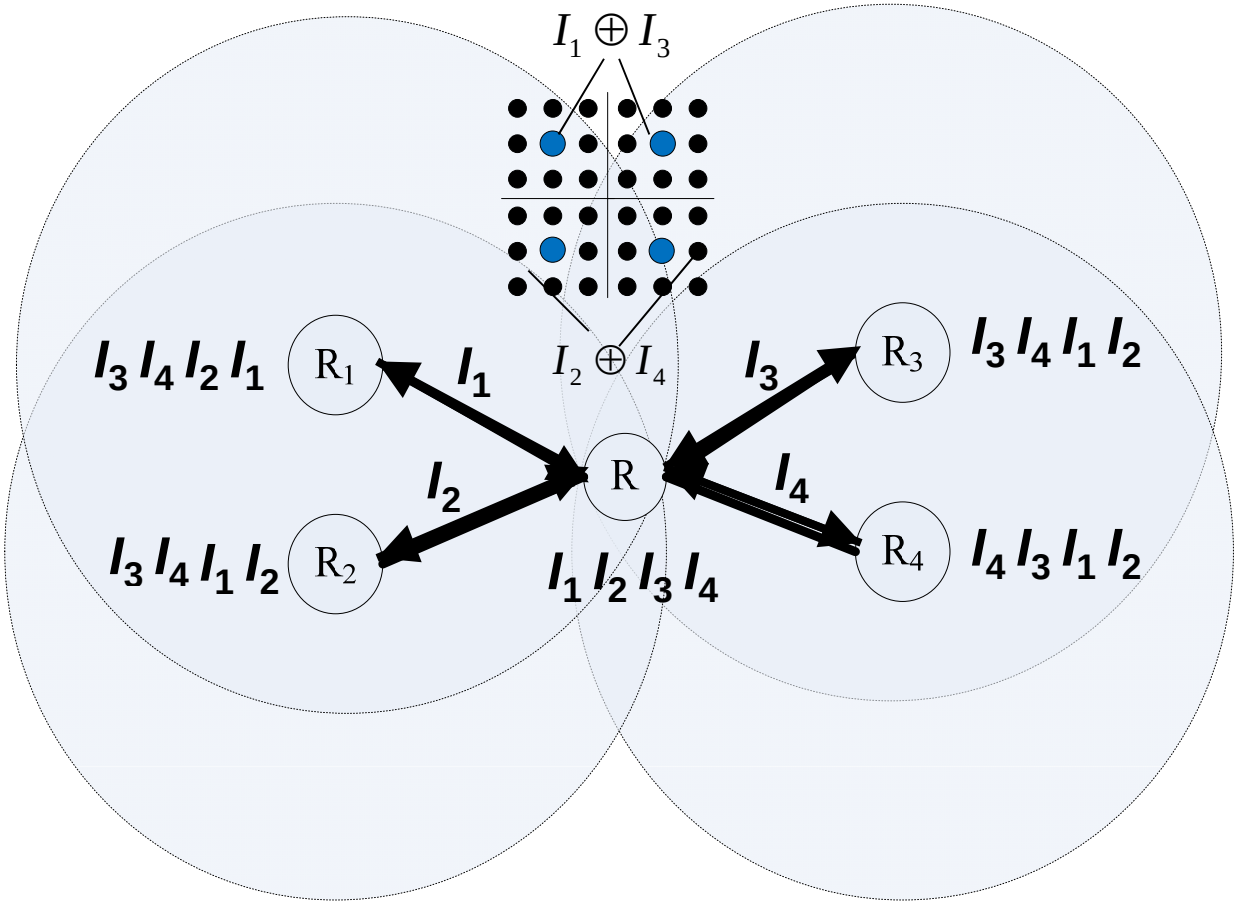
**Other Assumptions**

- Firstly, each node can overhear the data broadcasted from its neighbor nodes.
- Secondly, the nodes cannot overhear the packets from their neighbor nodes.

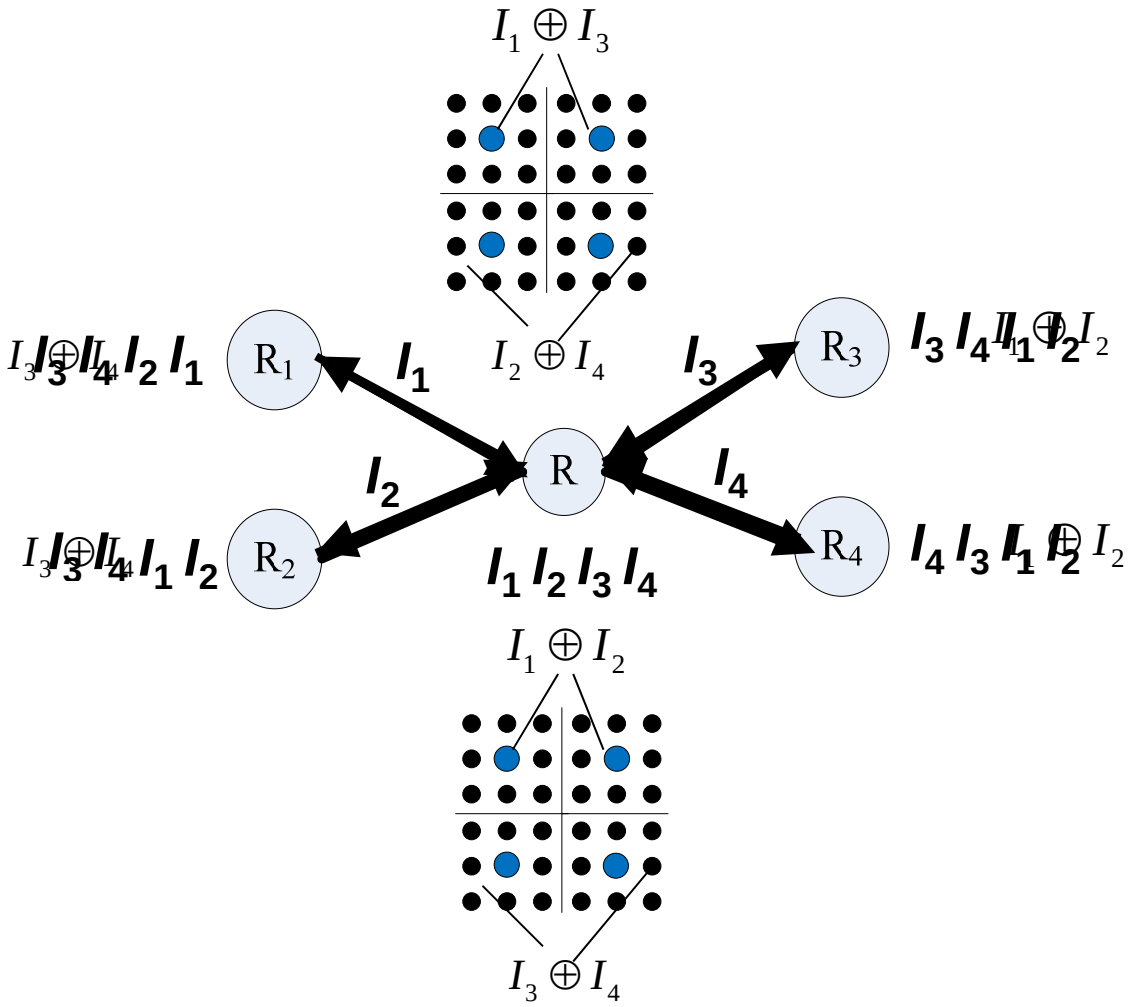
# Basic Idea


Node number increases
NC Scheme
Our Scheme
INSC
NC Scheme
Its benefit
become marginal
Save resource and
improve transmission
efficiency in two-way
relay network
TD Scheme
Low efficiency
Resource waste

# Basic Idea


$I_1 \oplus I_3$
$I_2 \oplus I_4$
R
R1
R2
R3
R4
$I_3 I_4 I_2 I_1$
$I_1$
$I_2$
$I_3$
$I_4$
$I_3 I_4 I_1 I_2$
$I_3 I_4 I_1 I_2$
$I_1 I_2 I_3 I_4$
$I_4 I_3 I_1 I_2$

# Basic Idea


$I_1 \oplus I_3$
$I_2 \oplus I_4$
$I_3$ $I_4$ $I_1 \oplus I_2$
$I_3$ $I_4$ $I_2$ $I_1$
$I_3$ $I_4$ $I_1$ $I_2$
$I_4$ $I_3$ $I_1 \oplus I_2$
$I_1$ $I_2$ $I_3$ $I_4$
$I_1 \oplus I_2$
$I_3 \oplus I_4$
R
R1
R2
R3
R4
$I_1$
$I_2$
$I_3$
$I_4$

# Outline

- Introduction
- System Model
  - System Model and Assumptions
  - Basic Idea
- Analysis of the Proposed Scheme
- Simulation and Analysis
  - Scenario with overhearing between neighboring nodes
  - Scenario without overhearing between neighboring nodes
- Conclusion
- References

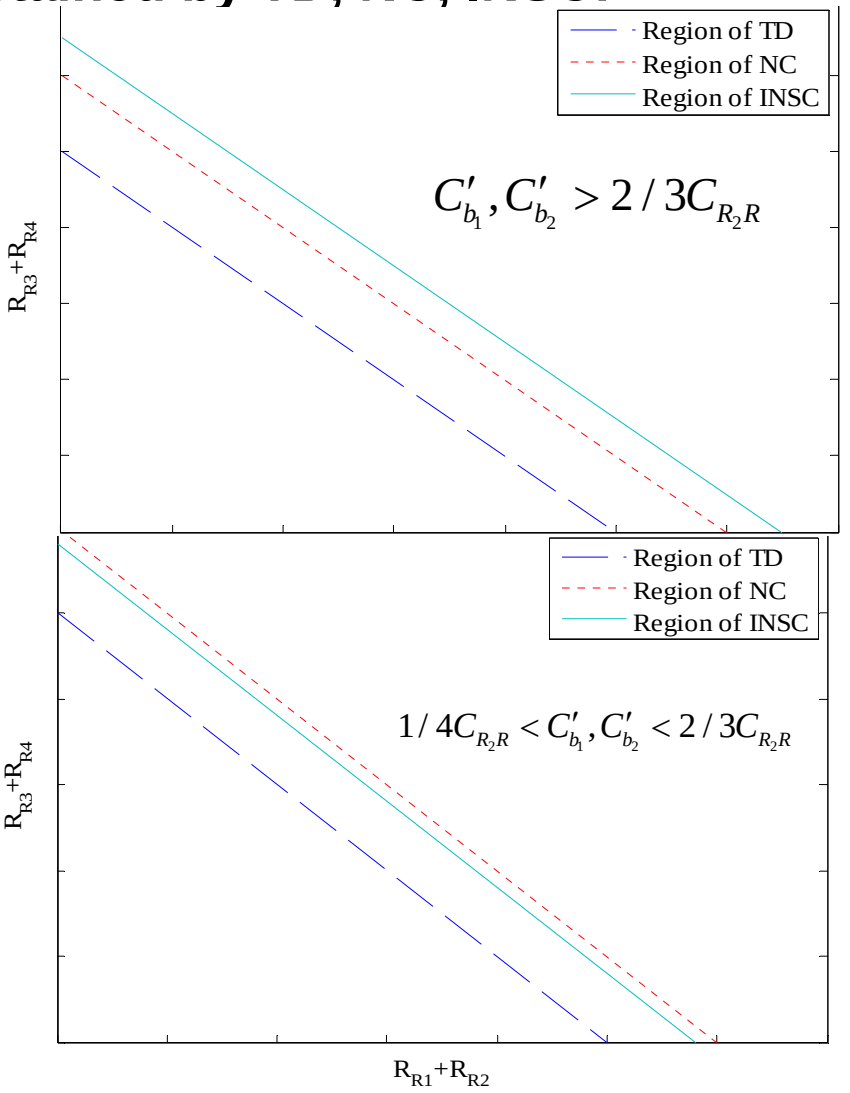
# Analysis of the Proposed Scheme

- **The achievable rate regions obtained by TD, NC, INSC:**

$$\Re = \left\{ \begin{array}{l} (R_{R_1} + R_{R_2}, R_{R_3} + R_{R_4}) : \sum_{j=1}^{8} \lambda_j = 1 \\ 0 < R_{R_1} \le \left\{ \lambda_1 C_{R_1 R}, \lambda_5 C_{R R_3} \right\}, 0 < R_{R_1} \le \left\{ \lambda_1 C_{R_1 R}, \lambda_5 C_{R R_4} \right\}, \\ 0 < R_{R_2} \le \left\{ \lambda_2 C_{R_2 R}, \lambda_6 C_{R R_3} \right\}, 0 < R_{R_2} \le \left\{ \lambda_2 C_{R_2 R}, \lambda_6 C_{R R_4} \right\}, \\ 0 < R_{R_3} \le \left\{ \lambda_3 C_{R_3 R}, \lambda_7 C_{R R_1} \right\}, 0 < R_{R_3} \le \left\{ \lambda_3 C_{R_3 R}, \lambda_7 C_{R R_2} \right\}, \\ 0 < R_{R_4} \le \left\{ \lambda_4 C_{R_4 R}, \lambda_8 C_{R R_1} \right\}, 0 < R_{R_4} \le \left\{ \lambda_4 C_{R_4 R}, \lambda_8 C_{R R_2} \right\} \end{array} \right\}$$

$$\Re = \left\{ \begin{array}{l} (R_{R_1} + R_{R_2}, R_{R_3} + R_{R_4}) : \sum_{j=1}^{6} \lambda_j = 1 \\ 0 < R_{R_1} \le \left\{ \lambda_1 C_{R_1 R}, \lambda_5 C_{b_1} \right\}, 0 < R_{R_2} \le \left\{ \lambda_2 C_{R_2 R}, \lambda_6 C_{b_2} \right\}, \\ 0 < R_{R_3} \le \left\{ \lambda_3 C_{R_3 R}, \lambda_5 C_{b_1} \right\}, 0 < R_{R_4} \le \left\{ \lambda_4 C_{R_4 R}, \lambda_6 C_{b_2} \right\} \end{array} \right\}$$

$$\Re = \left\{ \begin{array}{l} (R_{R_1} + R_{R_2}, R_{R_3} + R_{R_4}) : \sum_{j=1}^{5} \lambda_j = 1 \\ 0 < R_{R_1} \le \left\{ \lambda_1 C_{R_1 R}, \lambda_5 C'_{b_1} \right\}, 0 < R_{R_2} \le \left\{ \lambda_2 C_{R_2 R}, \lambda_5 C'_{b_2} \right\}, \\ 0 < R_{R_3} \le \left\{ \lambda_3 C_{R_3 R}, \lambda_5 C'_{b_1} \right\}, 0 < R_{R_4} \le \left\{ \lambda_4 C_{R_4 R}, \lambda_5 C'_{b_2} \right\} \end{array} \right\}$$



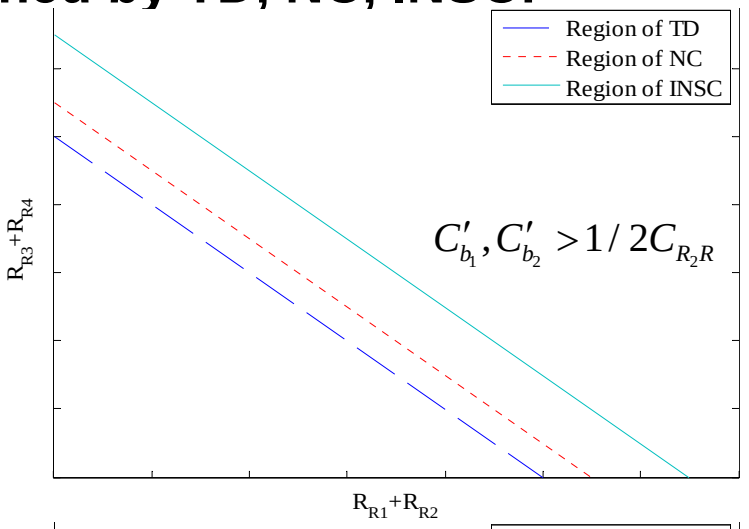
# Analysis of the Proposed Scheme

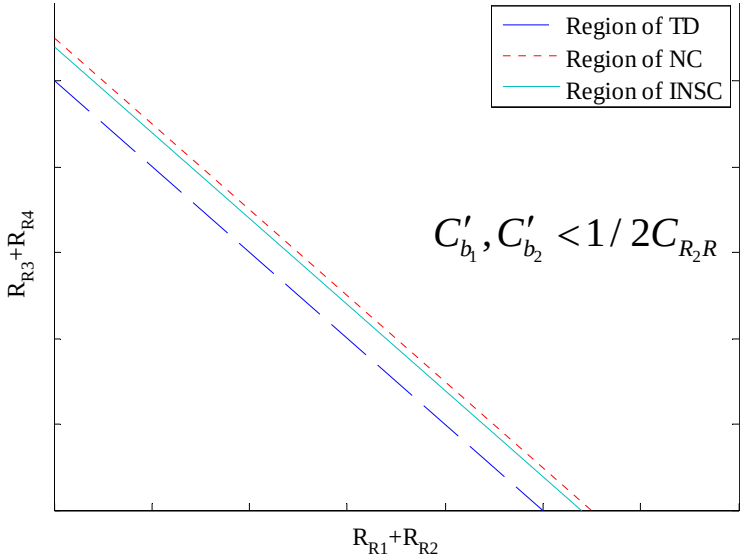
- **The achievable rate regions obtained by TD, NC, INSC:**

$$\Re=\left\{\begin{array}{l}(R_{R_1}+R_{R_2},R_{R_3}+R_{R_4}):\sum_{j=1}^{8}\lambda_j=1\\ 0<R_{R_1}\le\left\{\lambda_1C_{R_1R},\lambda_5C_{RR_2}\right\},0<R_{R_1}\le\left\{\lambda_1C_{R_1R},\lambda_5C_{RR_3}\right\},0<R_{R_1}\le\left\{\lambda_1C_{R_1R},\lambda_5C_{RR_4}\right\},\\ 0<R_{R_2}\le\left\{\lambda_2C_{R_2R},\lambda_6C_{RR_1}\right\},0<R_{R_2}\le\left\{\lambda_2C_{R_2R},\lambda_6C_{RR_3}\right\},0<R_{R_2}\le\left\{\lambda_2C_{R_2R},\lambda_6C_{RR_4}\right\},\\ 0<R_{R_3}\le\left\{\lambda_3C_{R_3R},\lambda_7C_{RR_1}\right\},0<R_{R_3}\le\left\{\lambda_3C_{R_3R},\lambda_7C_{RR_2}\right\},0<R_{R_3}\le\left\{\lambda_3C_{R_3R},\lambda_7C_{RR_4}\right\},\\ 0<R_{R_4}\le\left\{\lambda_4C_{R_4R},\lambda_8C_{RR_1}\right\},0<R_{R_4}\le\left\{\lambda_4C_{R_4R},\lambda_8C_{RR_2}\right\},0<R_{R_4}\le\left\{\lambda_4C_{R_4R},\lambda_8C_{RR_3}\right\}\end{array}\right\}$$

$$\Re=\left\{\begin{array}{l}(R_{R_1}+R_{R_2},R_{R_3}+R_{R_4}):\sum_{j=1}^{7}\lambda_j=1\\ 0<R_{R_1}\le\left\{\lambda_1C_{R_1R},\lambda_5C_{b_1}\right\},0<R_{R_1}\le\left\{\lambda_1C_{R_1R},\lambda_7C_{b_3}\right\},\\ 0<R_{R_2}\le\left\{\lambda_2C_{R_2R},\lambda_5C_{b_1}\right\},\\ 0<R_{R_3}\le\left\{\lambda_3C_{R_3R},\lambda_6C_{b_2}\right\},0<R_{R_3}\le\left\{\lambda_3C_{R_3R},\lambda_7C_{b_3}\right\},\\ 0<R_{R_4}\le\left\{\lambda_4C_{R_4R},\lambda_6C_{b_2}\right\}\end{array}\right\}$$

$$\Re=\left\{\begin{array}{l}(R_{R_1}+R_{R_2},R_{R_3}+R_{R_4}):\sum_{j=1}^{6}\lambda_j=1\\ 0<R_{R_1}\le\left\{\lambda_1C_{R_1R},\lambda_5C'_{b_1}\right\},0<R_{R_1}\le\left\{\lambda_1C_{R_1R},\lambda_6C'_{b_3}\right\},\\ 0<R_{R_2}\le\left\{\lambda_2C_{R_2R},\lambda_5C'_{b_1}\right\},0<R_{R_2}\le\left\{\lambda_2C_{R_2R},\lambda_6C'_{b_4}\right\},\\ 0<R_{R_3}\le\left\{\lambda_3C_{R_3R},\lambda_5C'_{b_2}\right\},0<R_{R_3}\le\left\{\lambda_3C_{R_3R},\lambda_6C'_{b_3}\right\},\\ 0<R_{R_4}\le\left\{\lambda_4C_{R_4R},\lambda_5C'_{b_2}\right\},0<R_{R_4}\le\left\{\lambda_4C_{R_4R},\lambda_6C'_{b_4}\right\}\end{array}\right\}$$



# Analysis of the Proposed Scheme

- **In the scenario with overhearing, the maximum sum rates of different schemes are:**
-

$$R_*^{TD} = (1+\mu)\left(\frac{1}{\max\left\{\frac{1}{1/C_{R_1R_3}+1/C_{R_1R_4}},\frac{1}{1/C_{R_2R_3}+1/C_{R_2R_4}}\right\}}+\frac{\mu}{\max\left\{\frac{1}{1/C_{R_3R_1}+1/C_{R_3R_2}},\frac{1}{1/C_{R_4R_1}+1/C_{R_4R_2}}\right\}}\right)^{-1}$$

$$R_*^{NC} = (1+\mu)\left(\frac{1}{\max\left\{\frac{1}{1/C_{R_1R}+1/C_{b_1}},\frac{1}{1/C_{R_2R}+1/C_{b_2}}\right\}}+\frac{\mu}{\max\left\{\frac{1}{1/C_{R_3R}+1/C_{b_1}},\frac{1}{1/C_{R_4R}+1/C_{b_2}}\right\}}\right)^{-1}$$

$$R_*^{INSC} = (1+\mu)\left(\frac{1}{\max\left\{\frac{1}{1/C_{R_1R}+1/C'_{b_1}},\frac{1}{1/C_{R_2R}+1/C'_{b_2}}\right\}}+\frac{\mu}{\max\left\{\frac{1}{1/C_{R_3R}+1/C'_{b_1}},\frac{1}{1/C_{R_4R}+1/C'_{b_2}}\right\}}\right)^{-1}$$

# Outline

- Introduction
- System Model
  - System Model and Assumptions
  - Basic Idea
- Analysis of the Proposed Scheme
- Simulation and Analysis
  - Scenario with overhearing between neighboring nodes
  - Scenario without overhearing between neighboring nodes
- Conclusion
- References

# Simulation and Analysis

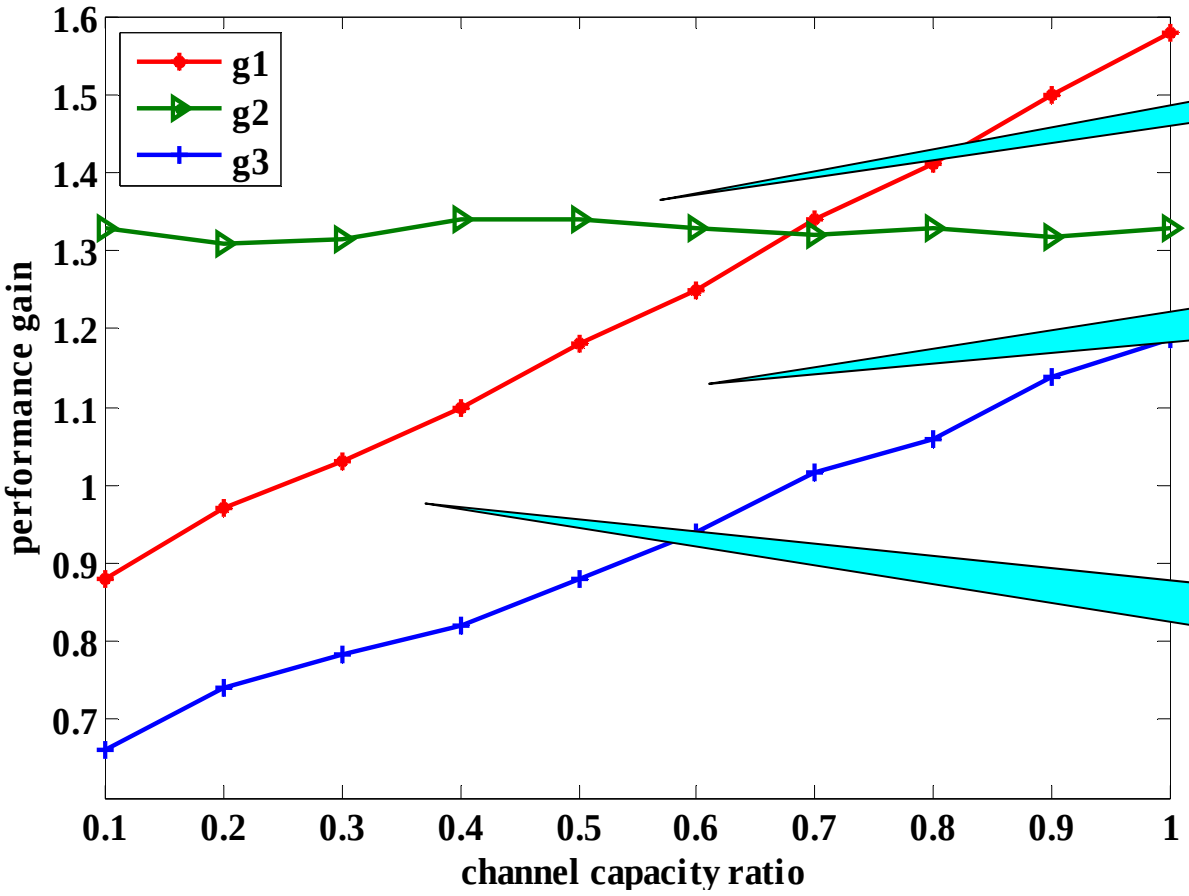
- Each node is assumed to have the same transmit power.
- The transmit powers on the basic and superposed constellations are well allocated.
- The ErcB channel model [17] is adopted to generate the channel gains between the relay node and all the source nodes.

| | |
|---|---|
| $R_1$ and $R_3$ | Higher channel gain |
| $R_2$ and $R_4$ | Lower channel gain |

- We set light on the performance gain of the INSC scheme over the conventional schemes to verify the analytical derivations.

$$g_1 = R_*^{INSC} / R_*^{TD} \quad g_2 = R_*^{NC} / R_*^{TD} \quad g_3 = g_1 / g_2 = R_*^{INSC} / R_*^{NC}$$

# Simulation and Analysis

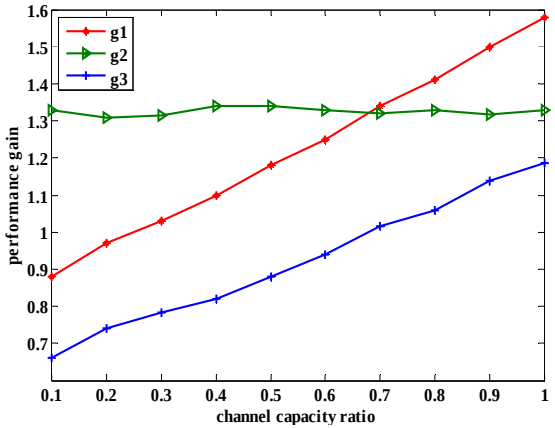


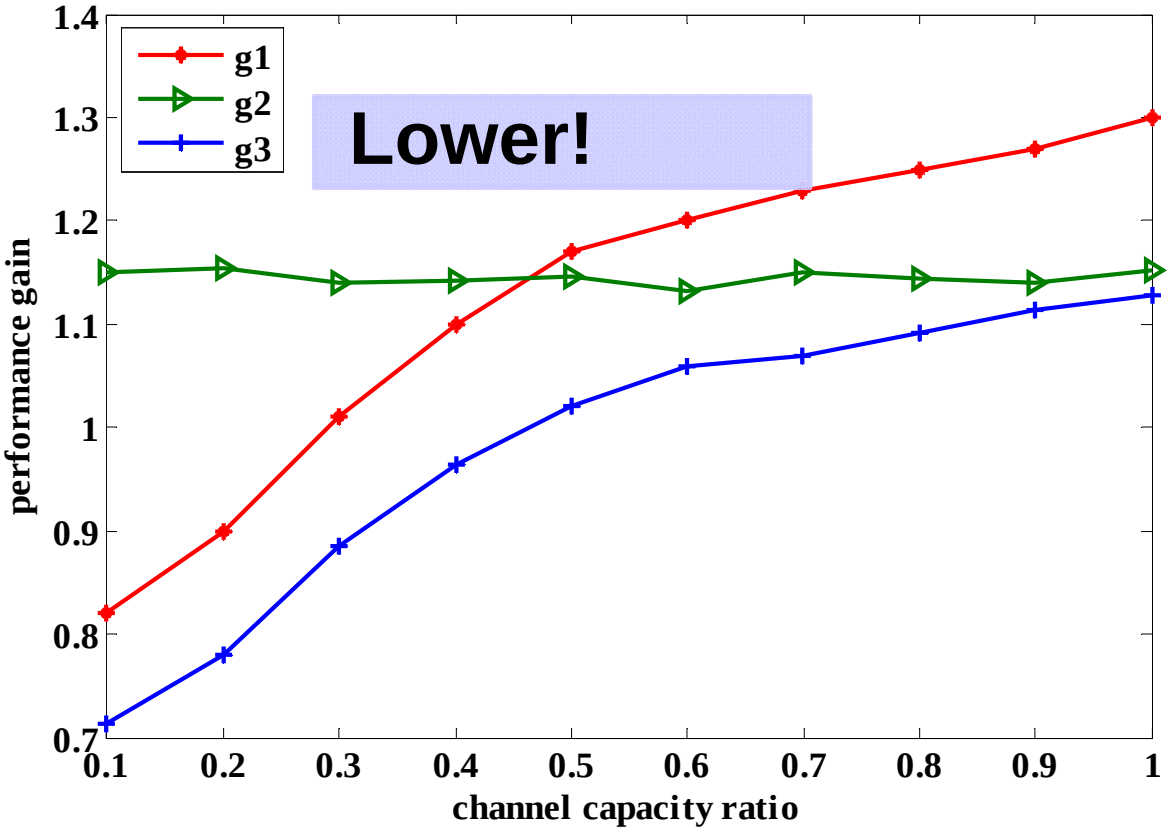

The gain of NC is independent to this channel capacity ratio.

SC technique can work better under relatively good channel condition.

Under poor channel condition, $g_1$ and $g_3$ is lower than 1, which accords with the theoretical analysis.

# Simulation and Analysis



# Outline

- Introduction
- System Model
  - System Model and Assumptions
  - Basic Idea
- Analysis of the Proposed Scheme
- Simulation and Analysis
  - Scenario with overhearing between neighboring nodes
  - Scenario without overhearing between neighboring nodes
- Conclusion
- References

# Conclusion

- **A novel information exchange scheme integrating NC with SC in extended two-way relay networks is proposed.**
  - **The scheme focuses on the information exchange among more than two nodes through relay node in fewer time slots.**
- **The INSC scheme is better than the other two schemes in some cases.**
  - **It is much more suitable for the good channel conditions in both the scenarios with and without overhearing.**

# References


1. R. Ahlswede, N. Cai, S. R. Li, and R. W. Yeung, “Network Information Flow”, IEEE Transactions on Information Theory, vol. 46, no. 4, pp.1204–1216, July 2000.
2. T. Ho, R. Koetter, M. Medard, D. Karger, and M. Effros, “The Benefits of Coding Over Routing in a Randomized Setting,” in Proc. of ISIT, 2003.
3. Y. Chen, S. Kishore and J. Li, “Wireless Diversity Through Network Coding,” in Proceedings of WCNC, Vol 3, Apr, 2006.
4. Y. Wu, P. A. Chou, and S.-Y. Kung, “Information exchange in wireless networks with network coding and physical-layer broadcast,” Technical Report MSR-TR-2004-78, Microsoft Research, Aug. 2004.
5. W. Pu, C. Luo, B. Jiao, F. Wu, “Natural Network Coding in Multi-hop Wireless Networks” in Proc. of ICC'08. pp.:2388 – 2392, May 2008.
6. S. Katti, H. Rahul, W. Hu, D. Katabi, M. M´adard, and J. Crowcroft, “XORs in the air: Practical wireless network coding,” in the Proc. Of ACM SIGCOMM Conf., Sep. 2006.
7. C. Hausl and J. Hagenauer, “Interative network coding and channel decoding for the two-way relay channel,” in Proc. of ICC'06, Jun. 2006.
8. P. Popovski and H. Yomo, “Physical network coding in two-way wireless relay channel,” in Proc. of ICC'07. pp. 707-712, Jun. 2007.
9. C.-H. Liu and F. Xue, “Network coding for two-way relaying: rate region, sum rate and opportunistic scheduling,” in Proc. of ICC '08. pp. 1044-1049, May 2008.

# References


10. S. Katti, I. Mari´c, A. Goldsmith, and *et al*, “Joint relaying and network coding in wireless networks,” Information Theory, 2007, ISIT’07, IEEE international Symposium on, pp. 1101-1105, Jun. 2007.
11. Li Chen, Wenwen Chen and et al. “The Method of Integrating Network Coding and Superposition Coding in Cooperative Relay System”[P], Chinese Patent: CN200810224527.7 Oct. 2008.
12. C. Liu and A. Arapostathis, “Joint Network Coding and Superposition Coding for Multi-User Information Exchange in Wireless Relaying Networks” in the Proc. of IEEE Global Communication Conference, Dec. 2008.
13. T. M. Cover and J. A. Thomas, Elements of Information Theory. John Wiley & Sons Inc., 1991.
14. P. Popovski, *et al.*, “Spectrally-Efficient Wireless Relaying based on Superposition Coding”, in Proc. of IEEE VTC2007. pp. 2936-294., April 2007.
15. V. Singh, “On superposition coding for wireless broadcast channels”, Master of Science Thesis, Stockholm, Sweden, Mar. 2005.
16. Dong Nguyen, Thinh Nguyen, and Bella Bose, .”Wireless broacast using network coding”,. in NetCod Workshop, january 2007.
17. V. Erceg and et al. “Channel models for fixed wireless applications”, in *http://www ieee802.org/16/tga/docs/80216a-03_01.pdf*, Jun. 2003.

# Thank you!