2011 1st semester
MIMO Communication Systems

#11: Distributed MIMO Networks

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Schedule (2nd half)

	Date	Text	Contents
#7	May 31	A-5	MIMO receiver
#8	June 7	A-3, 4	MIMO transmitter
#9	June 14	B-9	Adaptive commun. system
#10	June 21	A-6, B-14	Multi-user MIMO
#11	June 28	B-15, 16	Distributed MIMO networks
#12	July 5		Standardization of MIMO
	July 12		Final Examination

Agenda

- **Aim of today**

  Derive throughput performances
  of wireless networks with MIMO technology

- **Contents**

  - Classification of wireless networks
  - Wide zone
  - Cellular networks
    - Base station cooperation MIMO
  - Multi-hop networks
    - Two-way MIMO multi-hop relay

Warming Up

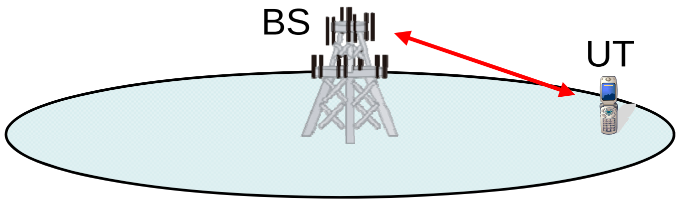
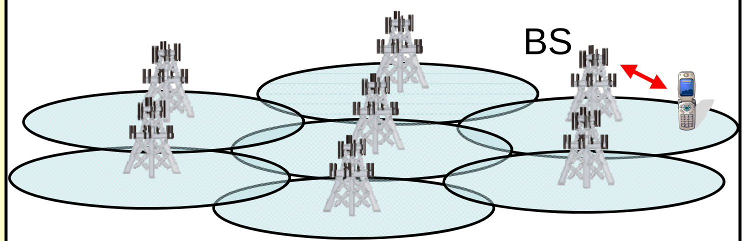
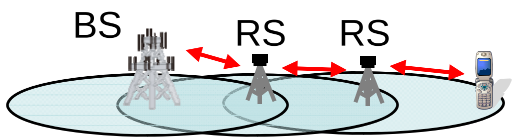
■ Question

Consider a scenario where speakers A&B are speaking to listeners A&B.
Classify the scenario into four cases & give features of each case.

Case A	Case B	Case C	Case D
Speakers A&B speak indipendent contents at the same time.	Speakers A&B speak indipendent contents alternately.	Listeners A&B have special ears to perform MIMO-MA.	Speakers A&B cooperatively speak to perform MIMO-BC.
?	?	?	?

Classification of Wireless Networks

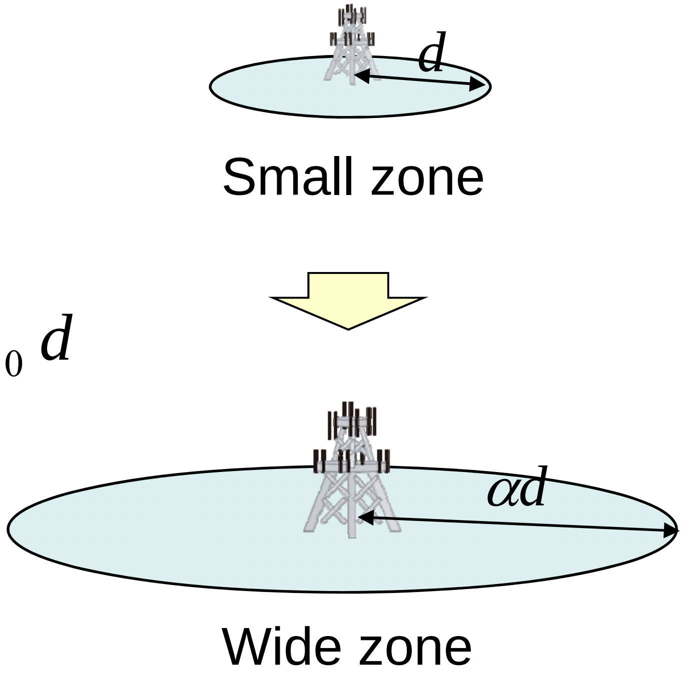
Wireless networks to achieve wide area coverage

	Architecture	System throughput	Drawbacks
Wide zone		Low	High power
Cellular network		High	Cost of base stations & backbone networks
Multi-hop network		Medium	Cost of relay stations

Wide Zone

SISO capacity

$$C = \log_2(1+\gamma) \qquad \gamma = \frac{|h|^2 P_{sz}}{\sigma^2}$$



Path loss model

Path loss decay

$$L_{sz}^{db} = 10\log_{10}\left(E[|h|^2]\right) = -34.5 - 35\log_{10} d$$

$$L_{wz}^{db} = -34.5 - 35\log_{10} d - 35\log_{10}\alpha$$

Required power

$$P_{wz}^{db} = P_{sz}^{db} + 35\log_{10}\alpha$$

Ex. $\alpha = 10 \qquad P_{sz} = 1\,[\mathrm{W}] \longrightarrow P_{wz} = 3\,[\mathrm{kW}]$

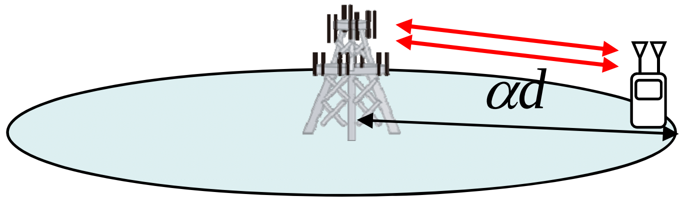
Wide Zone with MIMO

MIMO capacity

$$C_{\text{MIMO}} \cong MC_{\text{SISO}} \quad \text{if } \gamma >> 1$$

Rank of MIMO channel

$$= \log_2 (1+\gamma)^M \cong \log_2 \left(\gamma^M\right)$$



Wide zone with MIMO

Required power

$$\gamma_{\text{sz}}^{\text{dB}} = P_{\text{sz}}^{\text{dB}} - 34.5 - 35\log_{10} d - 10\log_{10}\sigma^2$$

$$\gamma_{\text{wzMIMO}}^{\text{db}} = M\left(P_{\text{wz}}^{\text{dB}} - 34.5 - 35\log_{10} d - 35\log_{10}\alpha - 10\log_{10}\sigma^2\right)$$

$$= M\left(\gamma_{\text{sz}}^{\text{dB}}\right) - 35M\log_{10}\alpha + MP_{+}^{\text{dB}} \longleftarrow \quad P_{\text{wz}}^{\text{db}} = P_{\text{sz}}^{\text{db}} + P_{+}^{\text{db}}$$

$$P_{+}^{\text{dB}} = 35\log_{10}\alpha - \gamma_{\text{sz}}^{\text{dB}}\left(1 - 1/M\right)$$

Ex. $\alpha = 10 \quad M = 2$

$P_{\text{sz}} = 1\,[\text{W}] \rightarrow P_{\text{wz}} = 317\,[\text{W}]$

Cellular Network

System capacity

$$C_{\mathrm{sys}} \cong N_{\mathrm{BS}} C$$

Number of BSs

Single cell capacity

Required cost

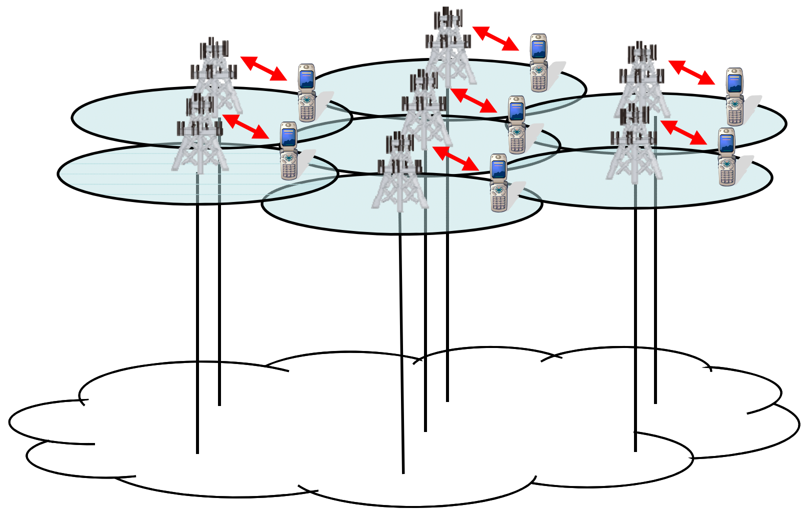
$$Y_{\mathrm{cell}} \cong N_{\mathrm{BS}} Y_{\mathrm{sz}} + Y_{\mathrm{bb}}$$

Cost of single BS

Cost of backbone

Problem of co-channel interference

Wireless Cellular network

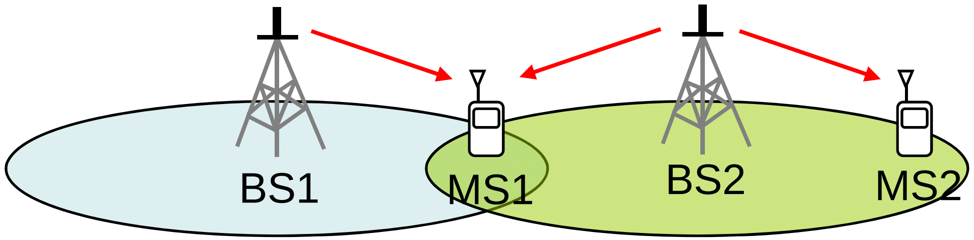


High speed backbone network

Co-channel Interference & Frequency Reuse

Signal model

$$y_1 = h_1 s_1 + h_2 s_2 + n_1$$



Single frequency network

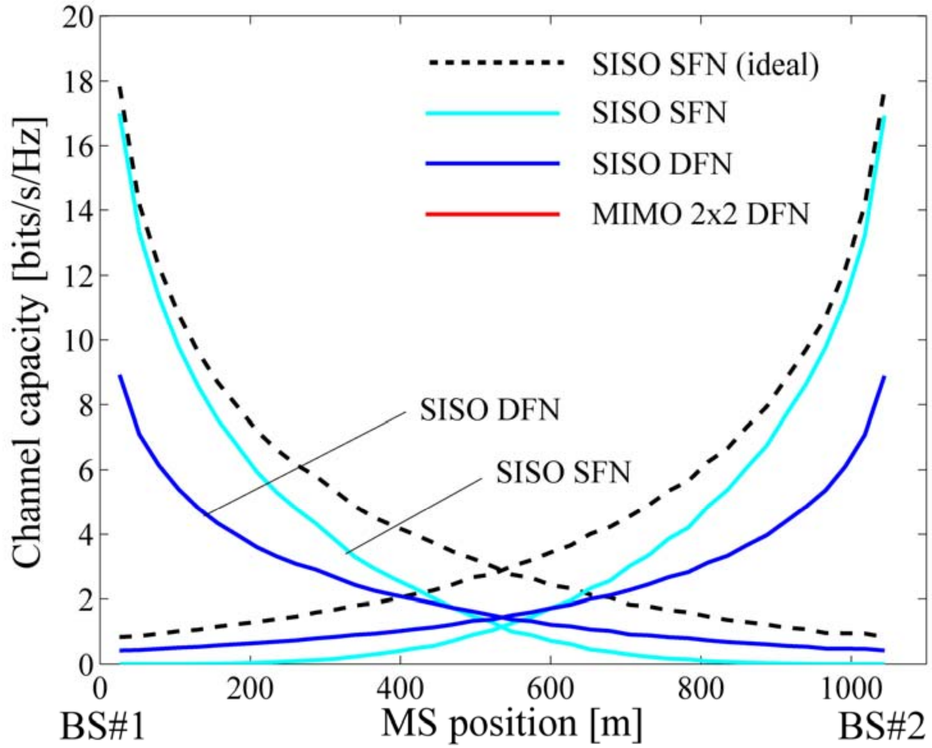
$$C_S = \log_2\left(1 + \frac{P_1|h_1|^2}{P_2|h_2|^2 + \sigma^2}\right)$$

Dual frequency network

Frequency reuse factor = 2

$$C_D = \frac{1}{2}\log_2\left(1 + \frac{P_1|h_1|^2}{\sigma^2}\right)$$

Loss of channelization



Cellular Network with MIMO

Signal model

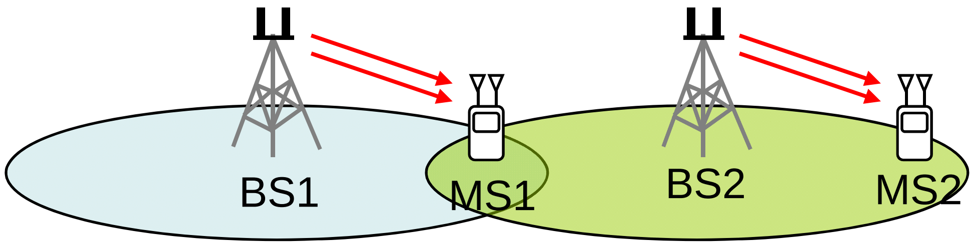
$$\mathbf{y}_1 = \mathbf{H}_1(f_1)\mathbf{s}_1 + \mathbf{n}_1$$
$$\mathbf{y}_2 = \mathbf{H}_2(f_2)\mathbf{s}_2 + \mathbf{n}_2$$

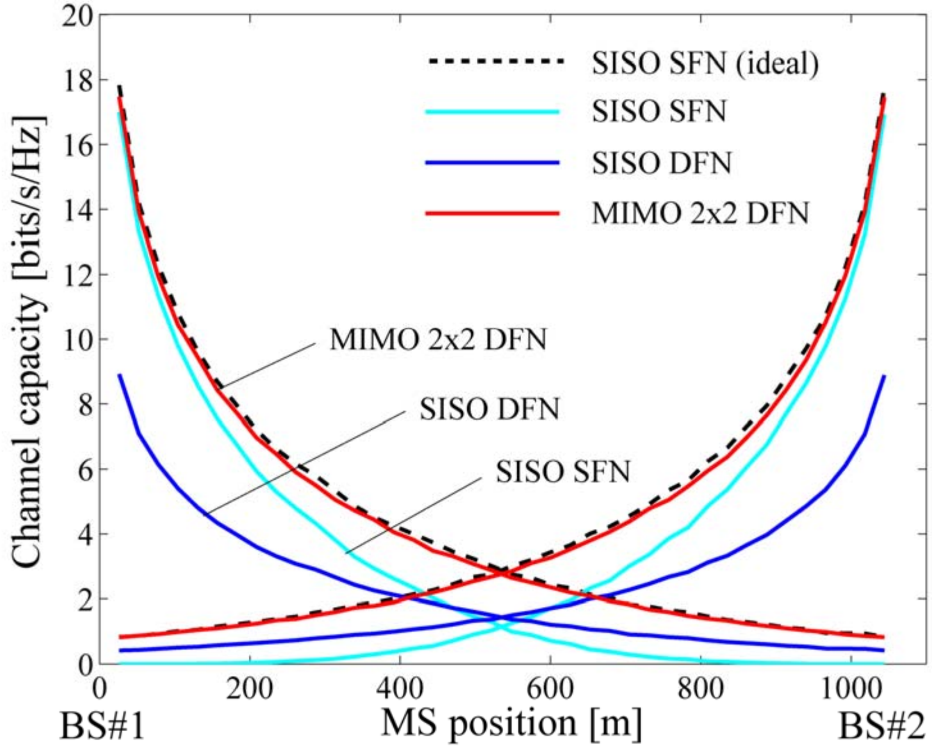
MIMO capacity

$$C_1 = \frac{1}{2}\log_2 \det\left(\mathbf{I} + \frac{P\mathbf{H}_1\mathbf{H}_1^H}{M_{\mathrm{BS}}\sigma^2}\right)$$

Number of BS antennas

Ideal SISO SFN = MIMO DFN





Eigenmode Analysis of Cellular MIMO

Eigenmode decomposition

$$\mathbf{H} = \mathbf{U}\Lambda\mathbf{V}^H$$

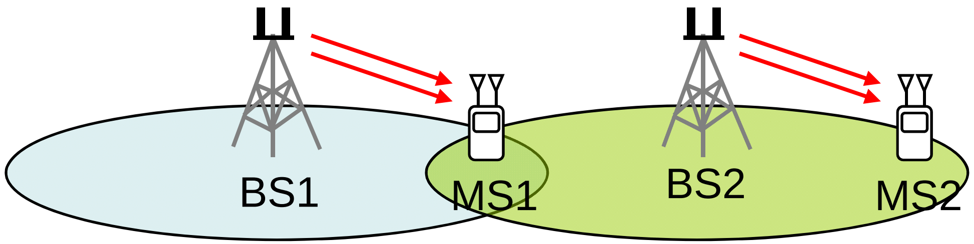
$$\Lambda = \mathrm{diag}[\sqrt{\lambda_1}, \cdots, \sqrt{\lambda_M}]$$

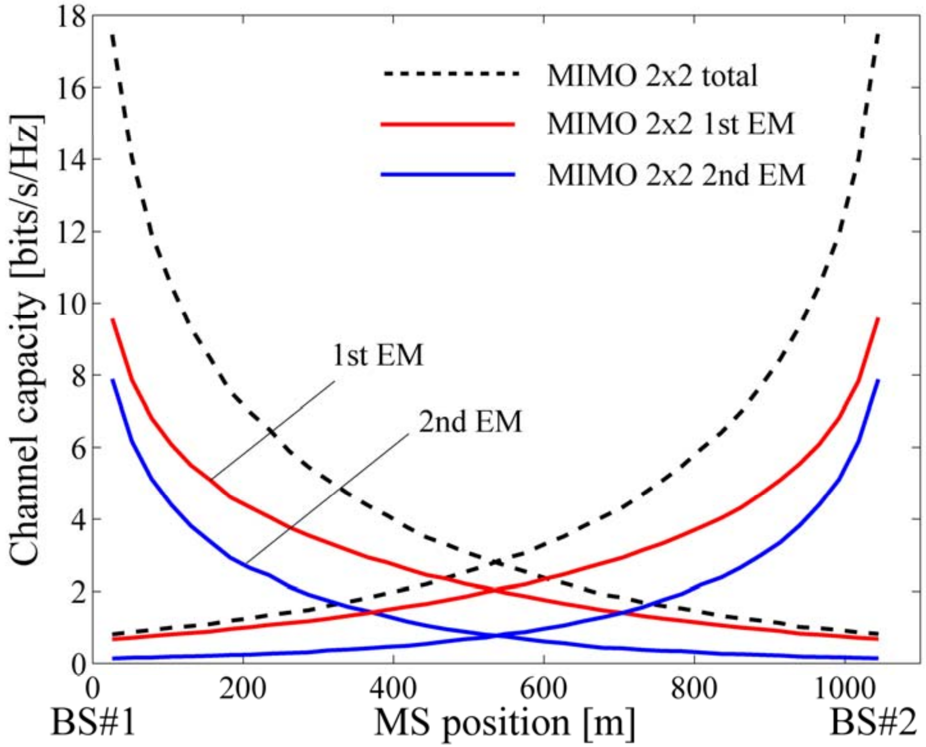
MIMO capacity

$$C = \sum_{i=1}^{M} C_i^{\mathrm{em}}$$

$$C_i^{\mathrm{em}} = \frac{1}{2}\log_2\left(1 + \frac{P\lambda_i}{M\sigma^2}\right)$$

2nd EM vanishes at cell edge





Cellular Network with Terminal Adaptive Array

Signal model

$$\mathbf{y}_1 = \mathbf{h}_1 s_1 + \mathbf{h}_2 s_2 + \mathbf{n}_1$$

Interference from BS2

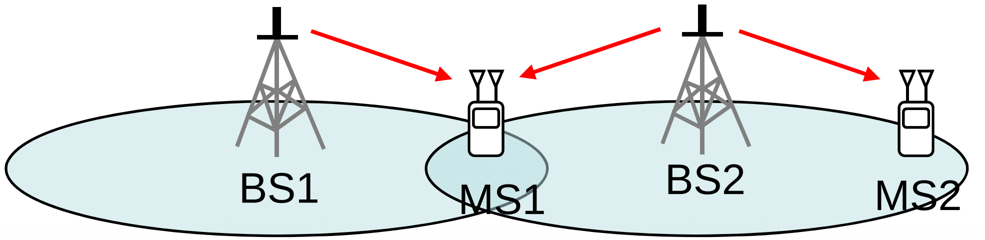
Terminal adaptive array

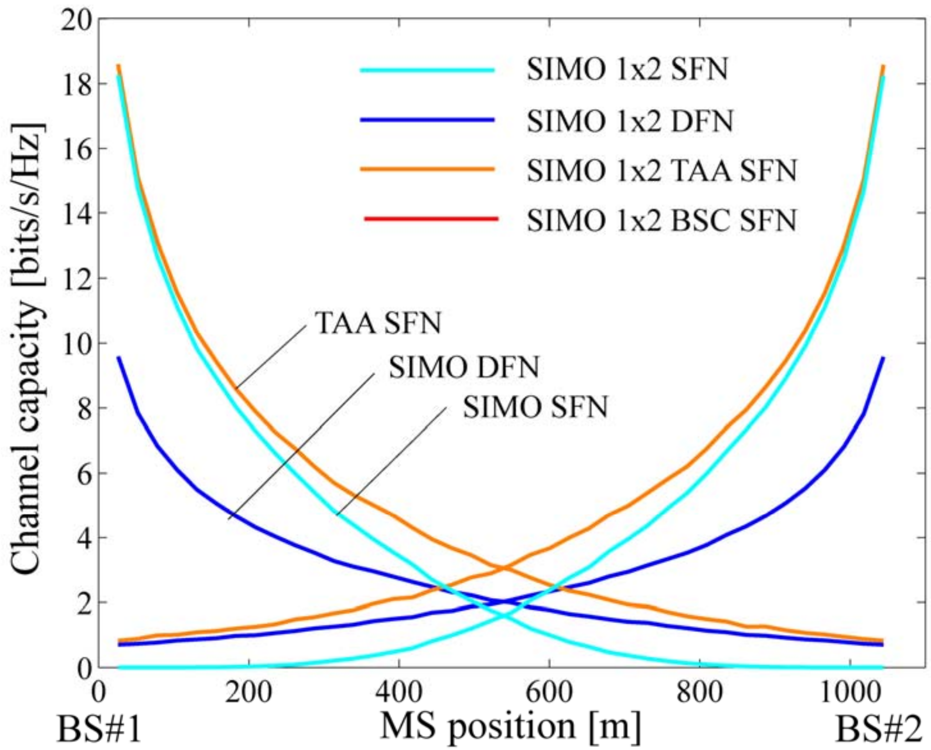
$$\mathbf{w}_1^{\mathrm{r}} = (\mathbf{h}_2)^{\perp}, \quad \mathbf{w}_2^{\mathrm{r}} = (\mathbf{h}_1)^{\perp}$$

Interference cancellation

$$\tilde{y}_1 = (\mathbf{w}_1^{\mathrm{r}})\mathbf{y}_1 = h_1^{\mathrm{e}} s_1 + \tilde{n}_1$$

Almost same with MIMO DFN





Cellular Network with Base Station Cooperation MIMO

Signal model

$$\mathbf{y} = \mathbf{h}_1 s_1 + \mathbf{h}_2 s_2 + \mathbf{n}$$

$$= \begin{bmatrix} \mathbf{h}_1 & \mathbf{h}_2 \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \mathbf{n}_1$$

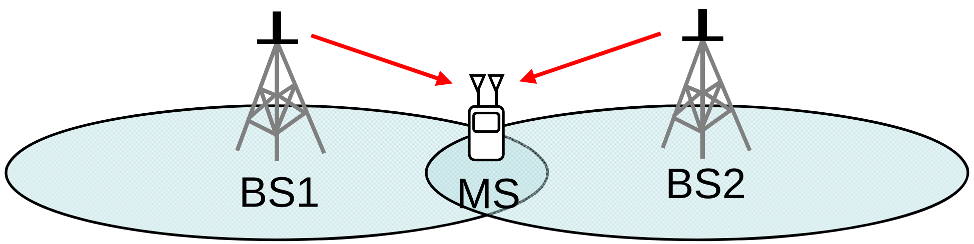
Cooperative MIMO channel

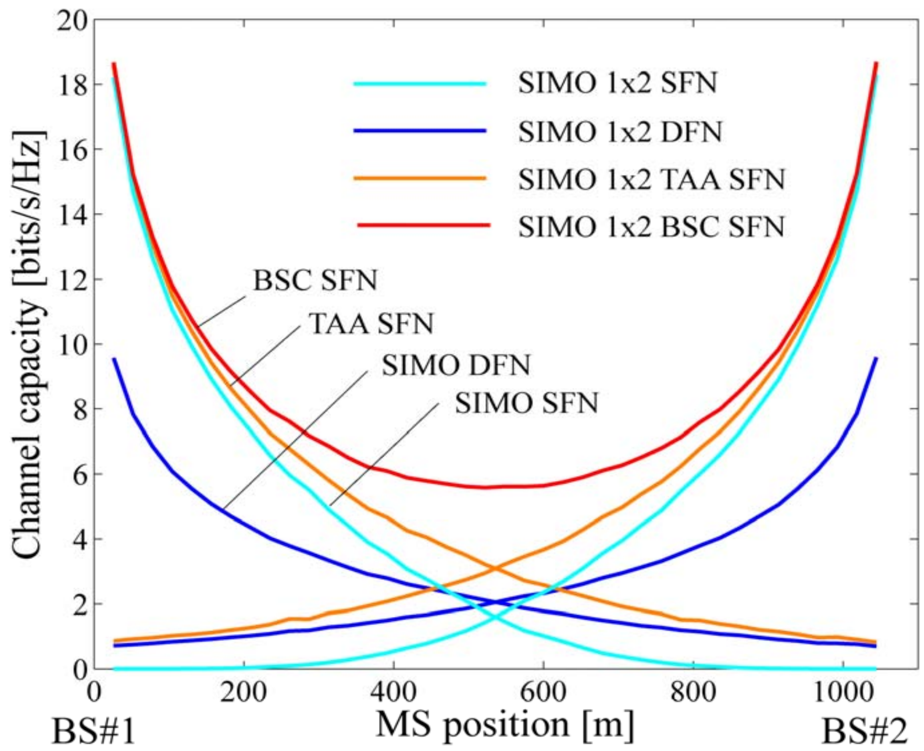
$$\mathbf{H} = \begin{bmatrix} \mathbf{h}_1 & \mathbf{h}_2 \end{bmatrix}$$

$$M = \min[N_{BS} M_{BS}, M_{MS}]$$

BSC MIMO capacity

$$C_{BSC} = \log_2 \det\left(\mathbf{I} + \frac{N_{BS} P \mathbf{H}\mathbf{H}^H}{M_{MS} \sigma^2} \right)$$





Eigenmode Analysis of Base Station Cooperation MIMO

Eigenmode decomposition

$$\mathbf{H} = [\mathbf{h}_1 \quad \mathbf{h}_2] = \mathbf{U}\Sigma\mathbf{V}^H$$

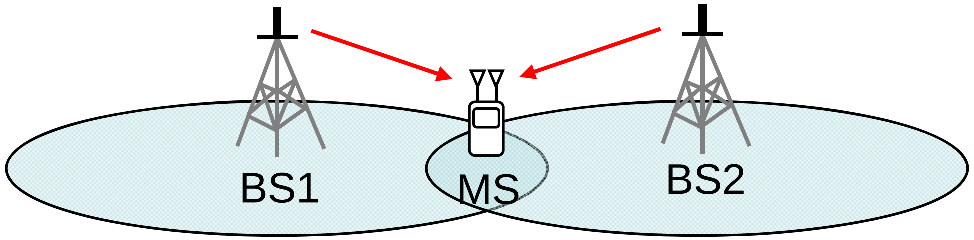
$$\Lambda = \mathrm{diag}[\sqrt{\lambda_1}, \cdots, \sqrt{\lambda_M}]$$

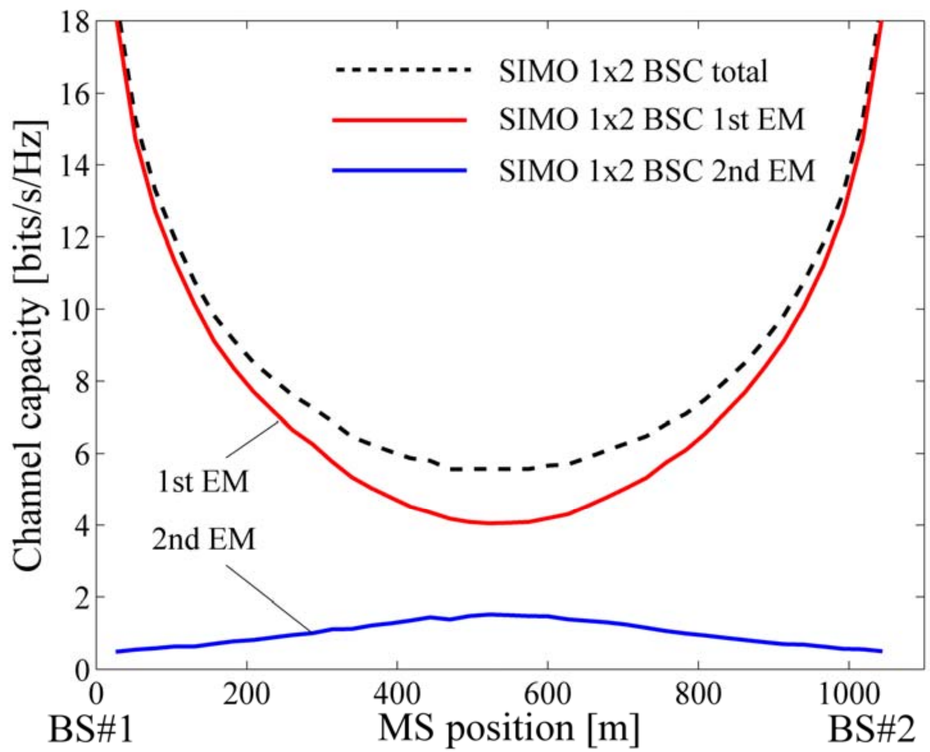
MIMO capacity

$$C = \sum_{i=1}^{M} C_i^{\mathrm{em}}$$

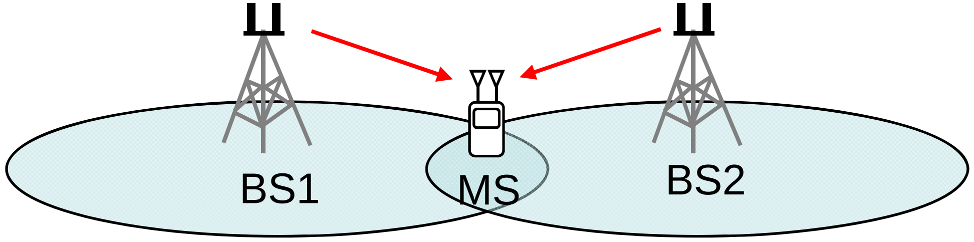
$$C_i^{\mathrm{em}} = \frac{1}{2}\log_2\left(1 + \frac{P\lambda_i}{M\sigma^2}\right)$$

2nd EM is effective at cell edge





Hybrid Normal MIMO & Base Station Cooperation MIMO



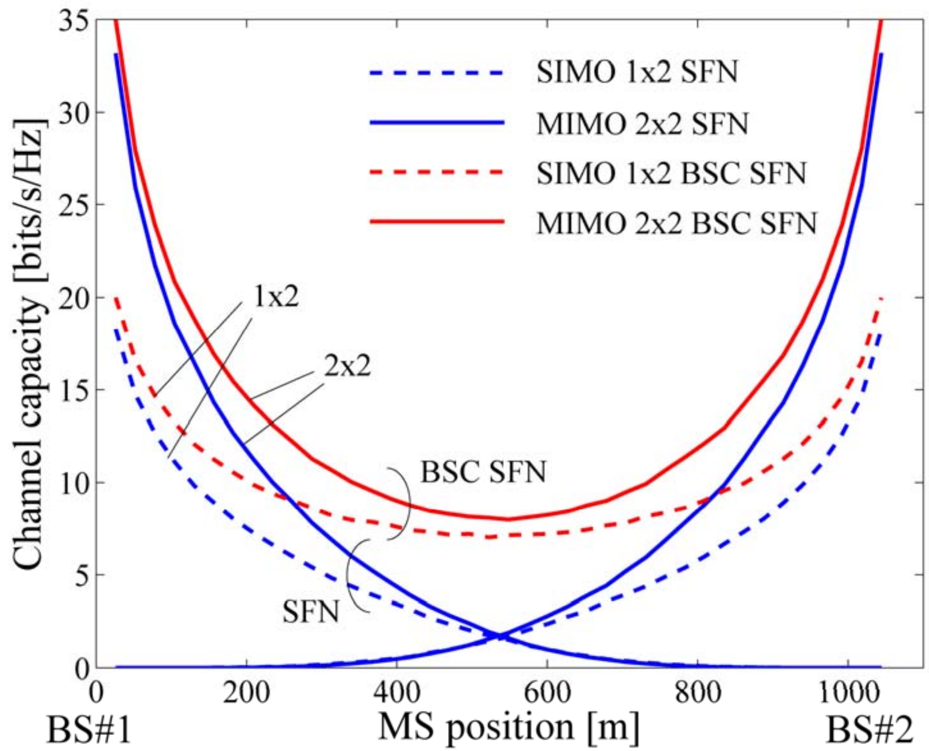
Signal model

$$\mathbf{y} = \mathbf{H}_1\mathbf{s}_1 + \mathbf{H}_2\mathbf{s}_2 + \mathbf{n}$$
$$= \begin{bmatrix} \mathbf{H}_1 & \mathbf{H}_2 \end{bmatrix} \begin{bmatrix} \mathbf{s}_1 \\ \mathbf{s}_2 \end{bmatrix} + \mathbf{n}$$

BSC MIMO capacity

$$C_{\mathrm{BSC}} = \log_2 \det\left(\mathbf{I} + \frac{N_{\mathrm{BS}} P \mathbf{H}\mathbf{H}^H}{M_{\mathrm{MS}} \sigma^2} \right)$$

- Normal MIMO at cell center
- Cooperation MIMO at cell edge



Multi-hop Relay Network

End-to-end capacity

$$C_{\text{mh}} \cong \frac{1}{2} C_{\text{sz}}$$

Loss of half duplex

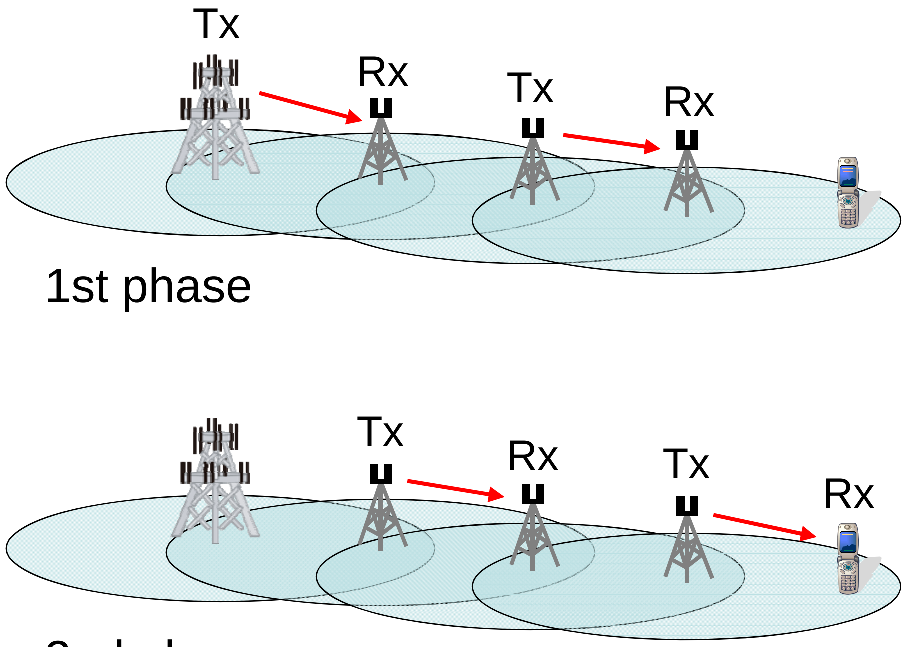
Required cost

$$Y_{\text{mh}} \cong (N_{\text{RS}} + 1) Y_{\text{sz}}$$

Number of relay stations

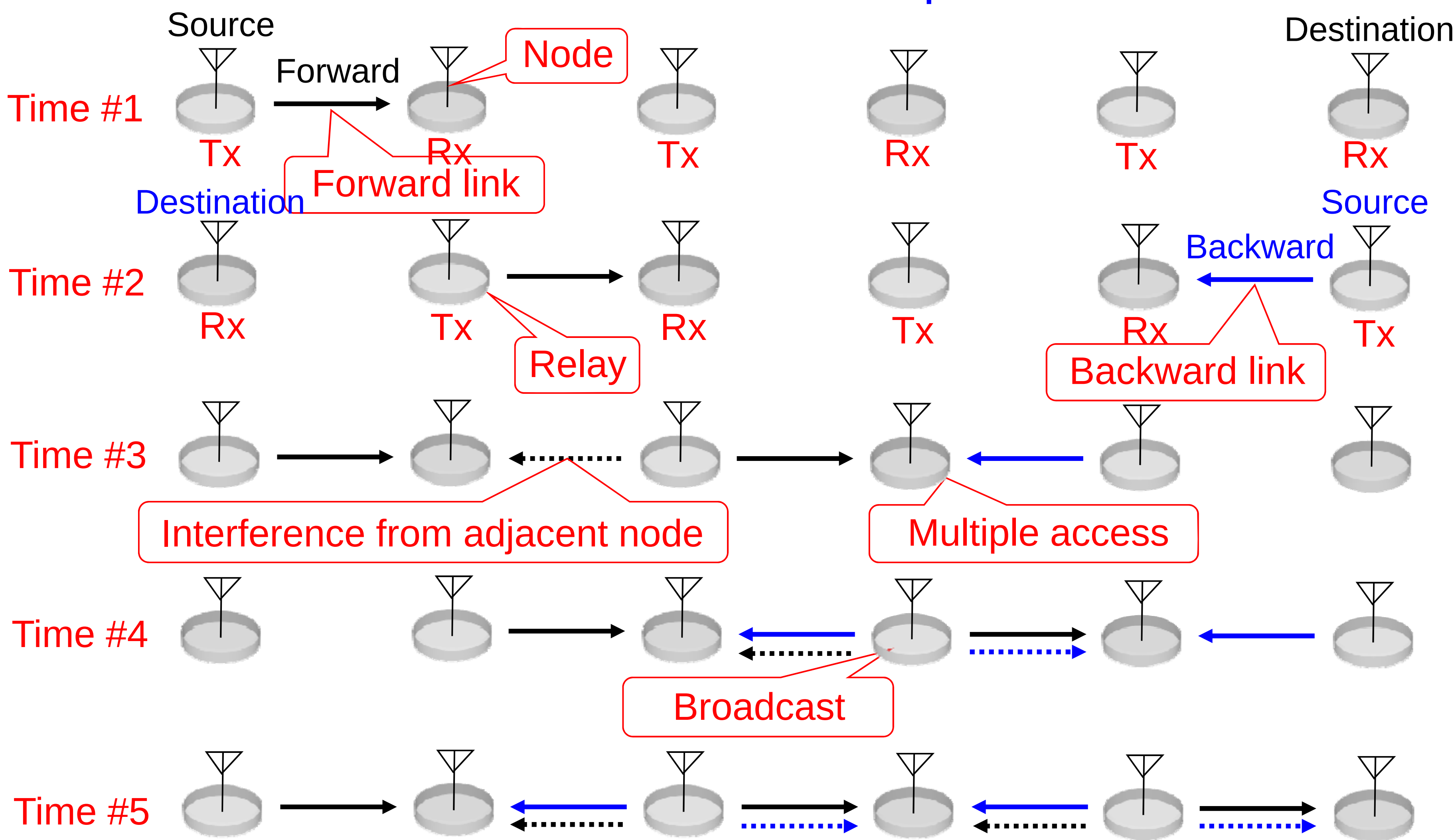
Problem of co-channel interference

Half duplex multi-hop network



Technology in multi-hop network

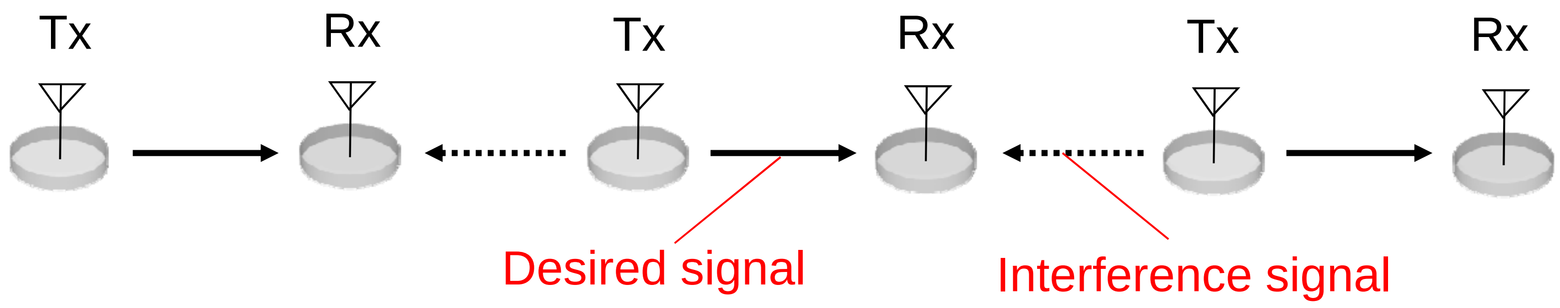
1-dimensional 6-node wireless multi-hop network



Multi-hop Relay with Frequency Reuse

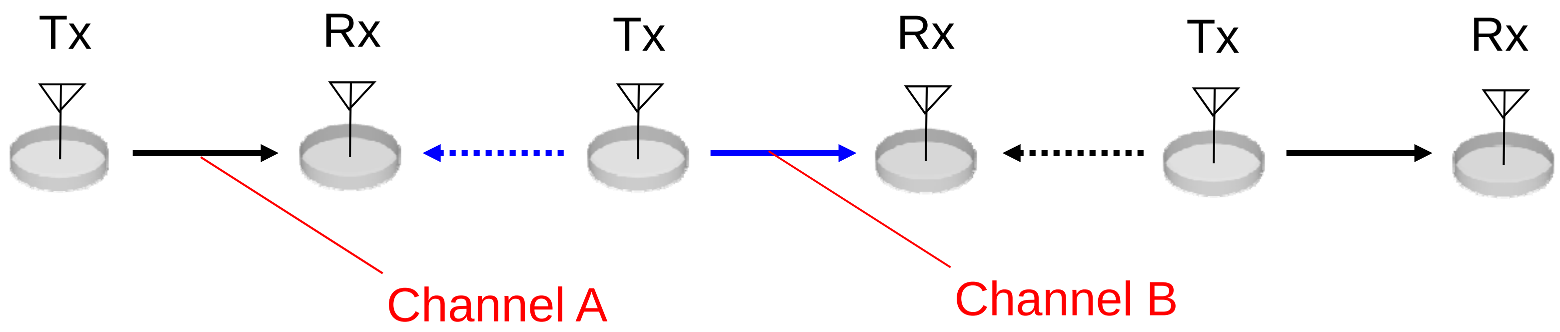
Single channel multi-hop network

Interference from adjacent node is severe



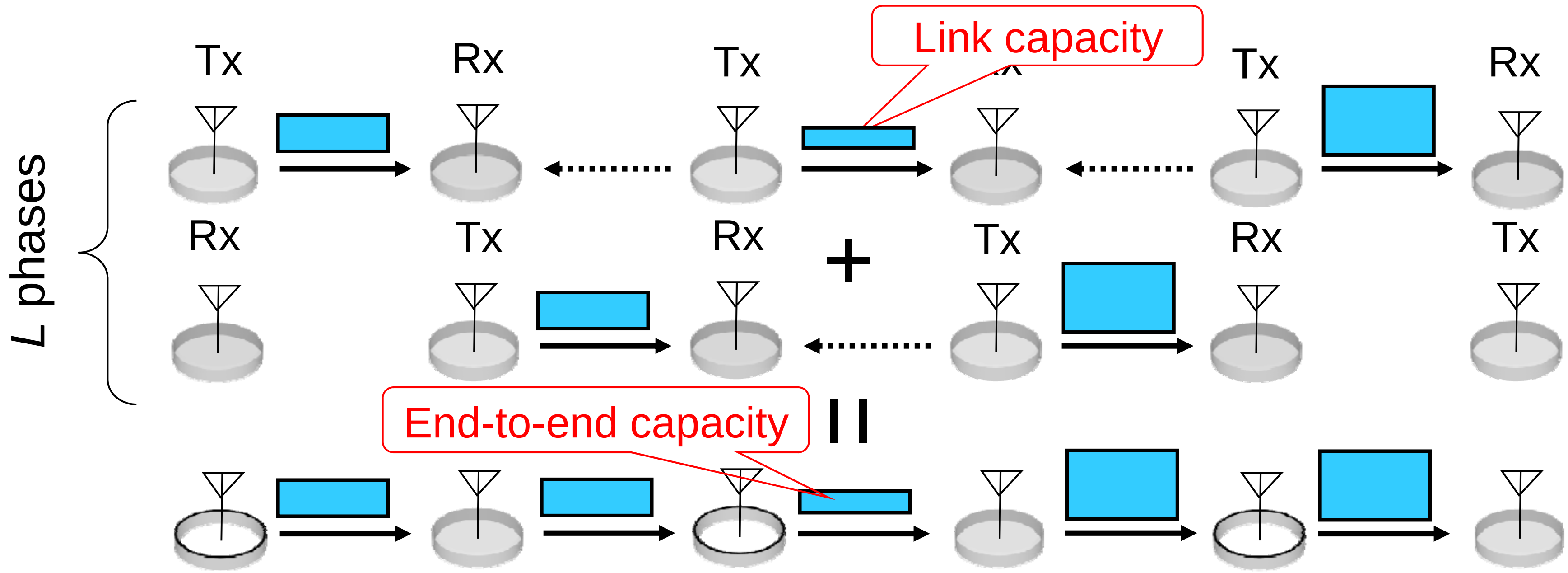
Multi channel multi-hop network

Channelization loss of 1/2



End-to-end capacity

End-to-end capacity for decode, spool, and forward network



- Link capacity

$$C_i^{\mathrm{av}} = \mathrm{E}\left[\log_2\left[1+\frac{P_i g_{(i+1)i}}{\sum_{j\neq i} P_j g_{(i+1)j}+\sigma^2}\right]\right]$$

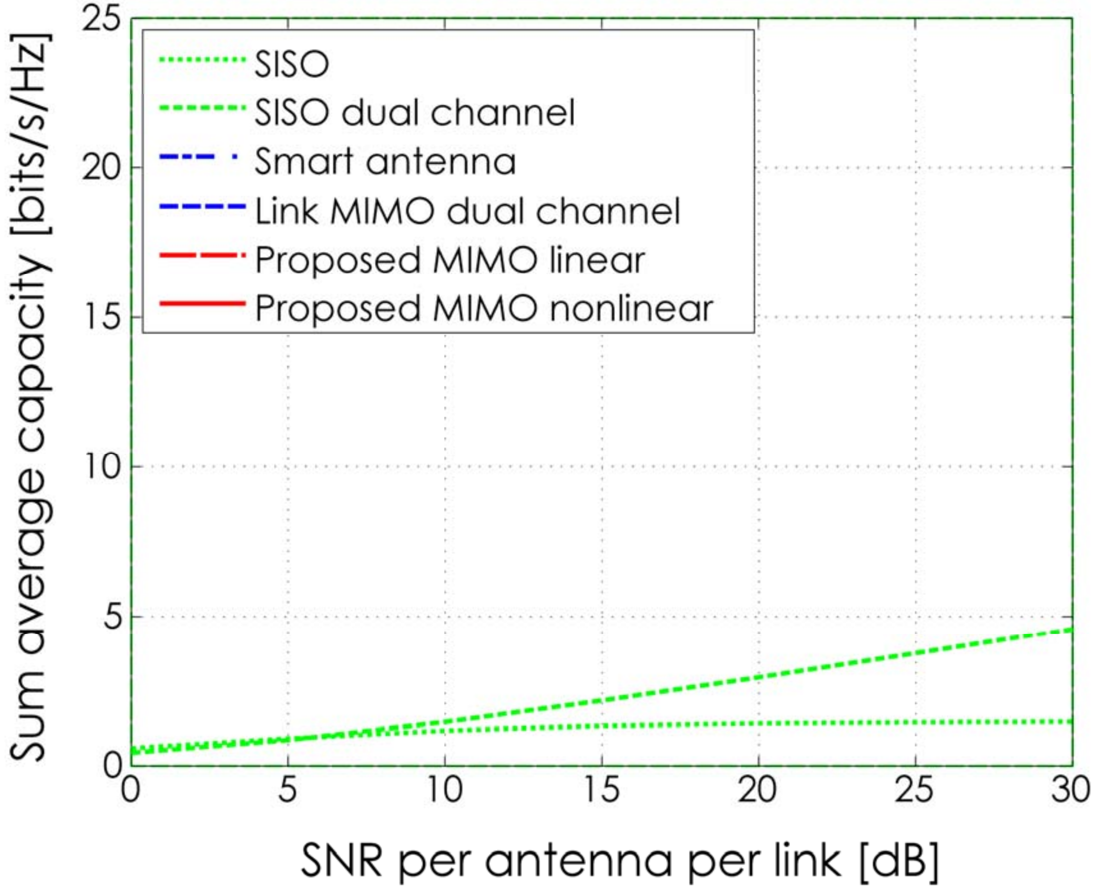
- End-to-end capacity

$$C_i^{\mathrm{av}} = \min\left[\frac{1}{L} C_i^{\mathrm{av}}\right]$$

E2E throughput performance

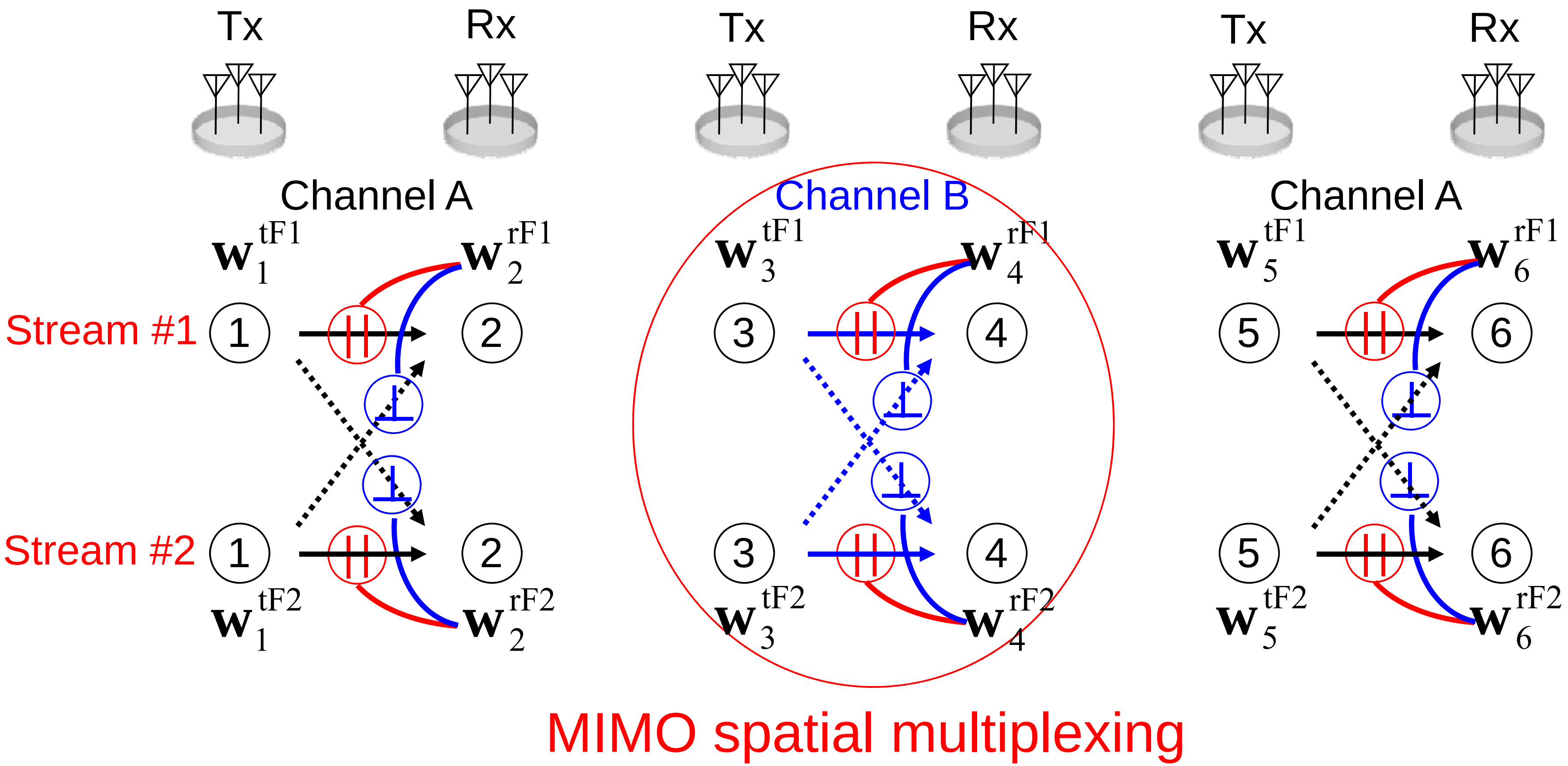
• Negligible throughput of single channel multi-hop network due to strong interference from adjacent node

• Introduction of multi-channel strategy improves the throughput performance



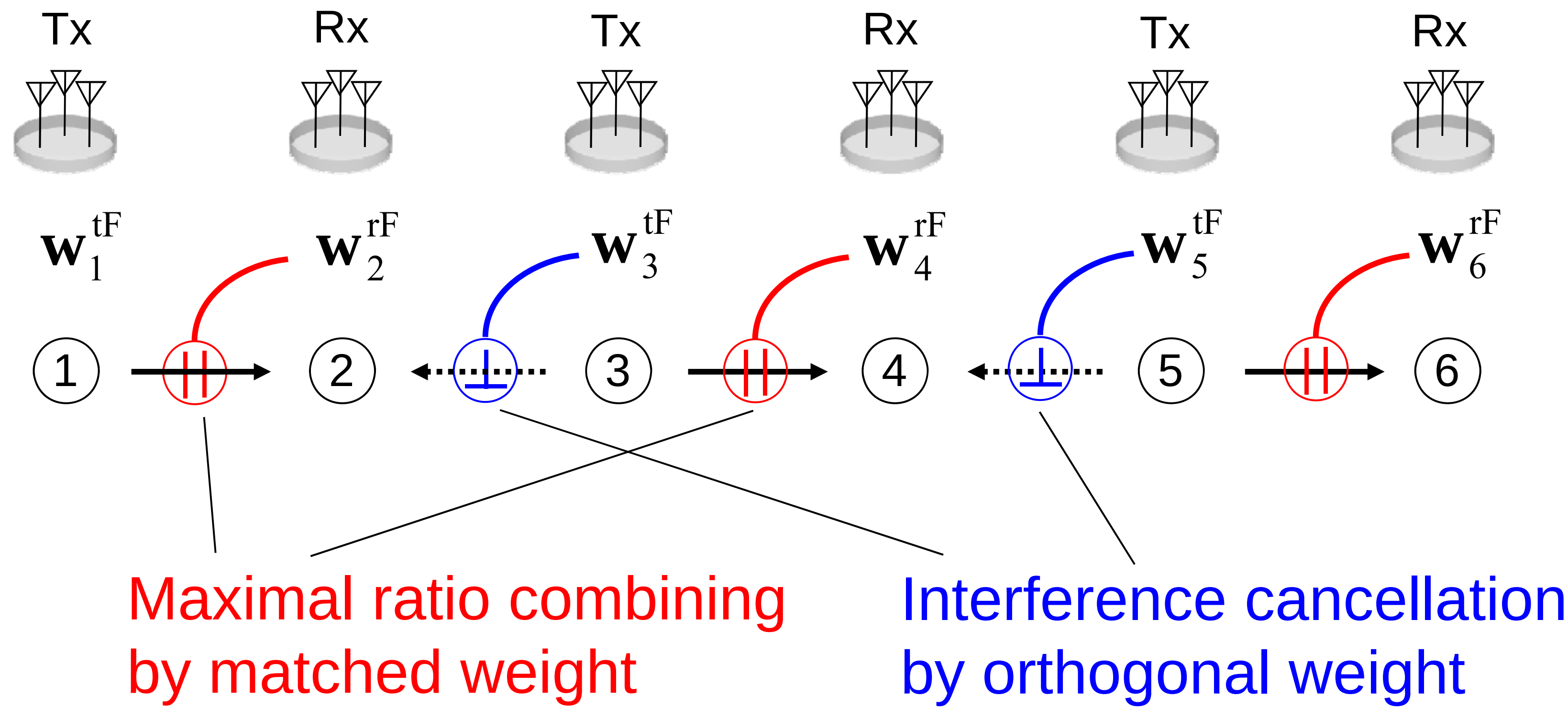
Multi-hop Relay with MIMO

- Increase spectral efficiency by spatial multiplexing within a link
- Recover the disadvantage of multi-channel networks



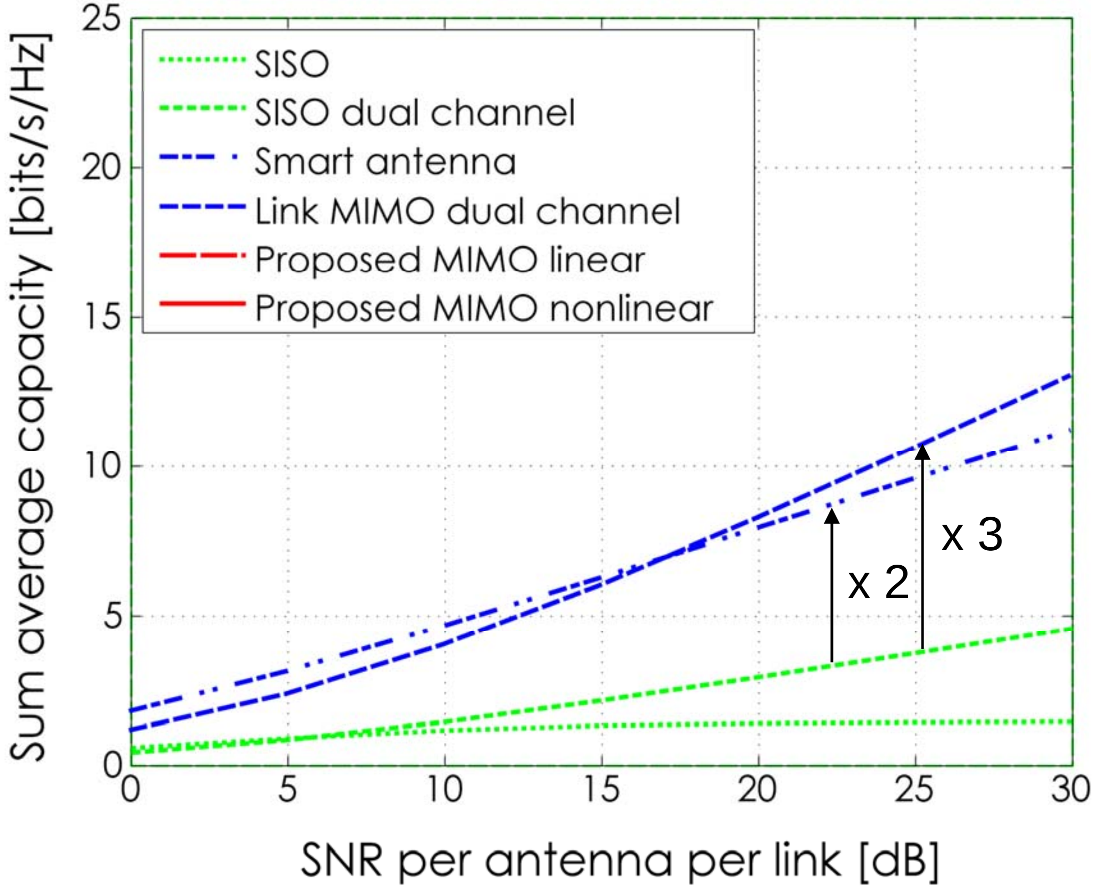
Multi-hop Relay with Adaptive Array

- Achieve transmit & receive interference cancellation and diversity
- Realize single channel multi-hop network



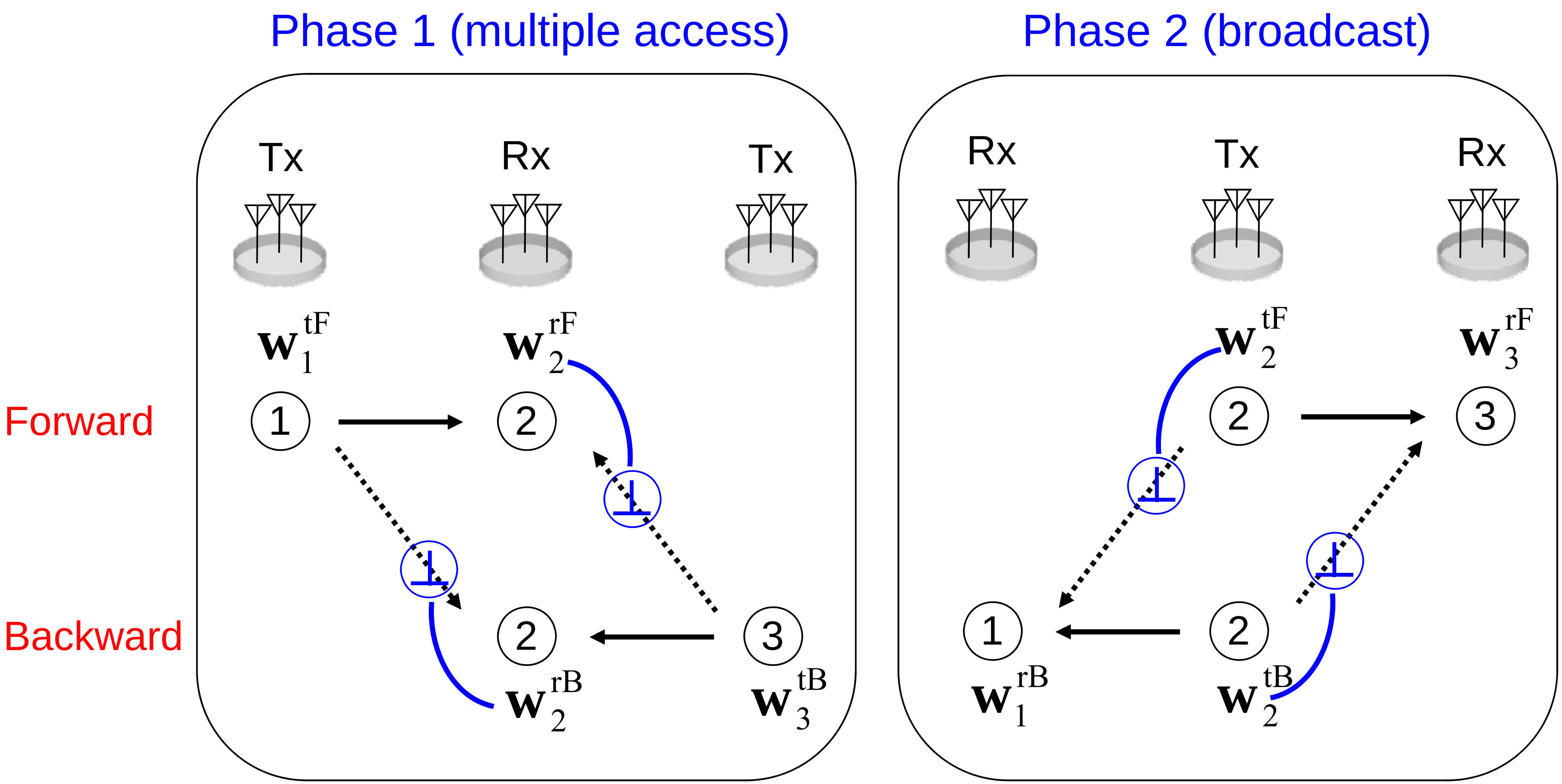
E2E throughput performance

- Throughput performance of link-by-link MIMO scales linearly with respect to the number of antennas per node
- Introduction of adaptive antenna compensates the channelization loss



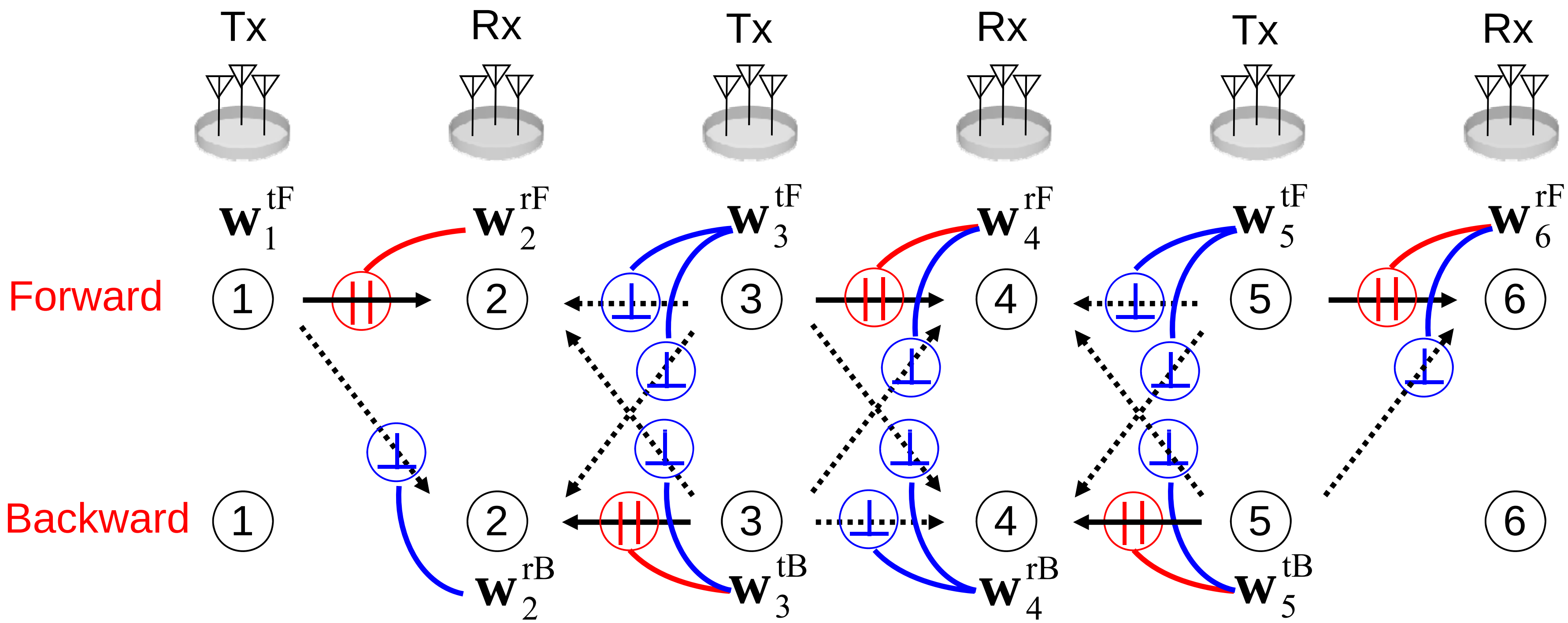
Two-way MIMO Relay (Two-hop)

- Two-way streams (forward & backward) are multiplexed in a relay network
- Recover the loss of half duplex by two-way multiplexing



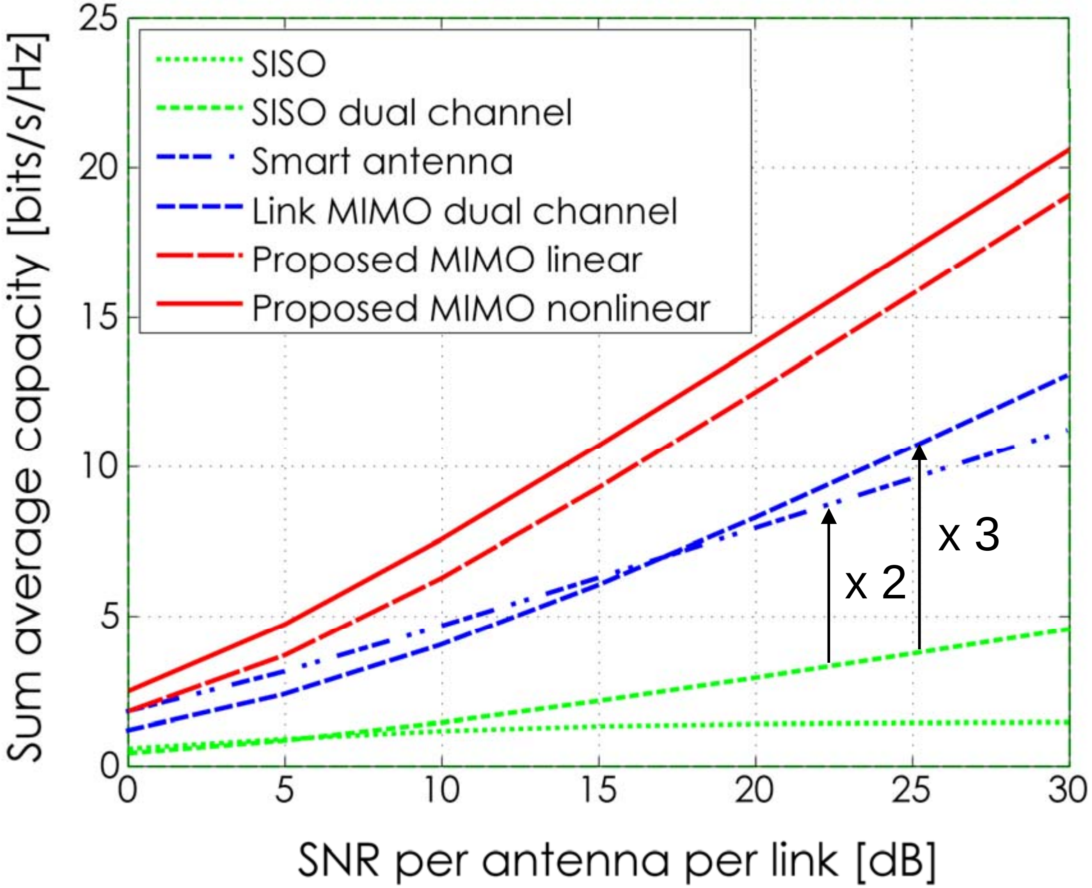
Two-way MIMO Multi-hop Relay

- Two-way transmission by spatial multiplexing of forward & backward streams
- Network oriented interference cancellation by a combination of transmit & receive weights
- Simultaneous realization of diversity, transmit & receive interference cancellation, and spatial multiplexing



E2E throughput performance

- Throughput performance of two-way MIMO multi-hop network is the best
- 2-times improvement due to realization of single channel network and further 2-times improvement due to two-way streams multiplexing



Multi-flow Multi-hop Relay Network

Network capacity

$$C_{\mathrm{mfmh}} \cong N_{\mathrm{flow}} C_{\mathrm{twmh}}$$

Number of flows

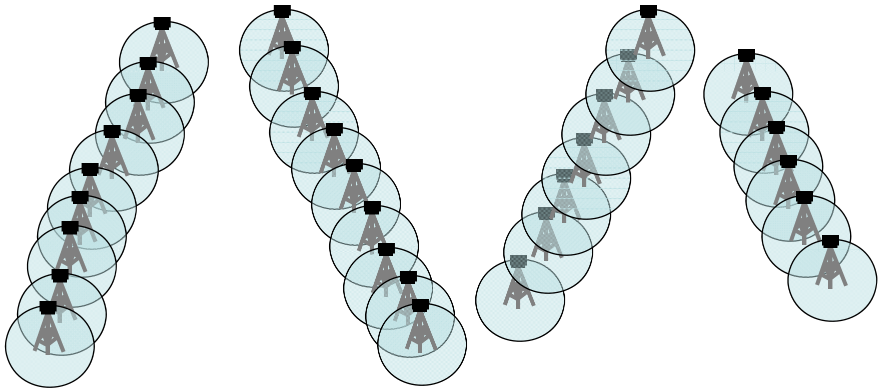
E2E capacity of two-way multi-hop network

Required cost

$$Y_{\mathrm{mfmh}} \cong N_{\mathrm{flow}} (N_{\mathrm{RS}} + 1) Y_{\mathrm{sz}}$$

Effective for local networks

Co-existence of several flows of multi-hop network



Power reduced multi-hop networks

Summary

- Distributed MIMO networks
  - Wireless networks to achieve wide area coverage
    - Wide zone, cellular networks, multi-hop networks
  - Link-by-link application of single user MIMO is not efficient
  - Base station cooperation MIMO cellular network
    - Cooperative MIMO to achieve better performance at cell edge
  - Two-way MIMO multi-hop relay
    - Network MIMO to achieve single channel two-way relay

Application of MIMO technology to commercial products

Standardization of MIMO in IEEE & 3GPP