An Overview of Wireless Cooperative Networks

Real Egoistic Behavior is Cooperation!

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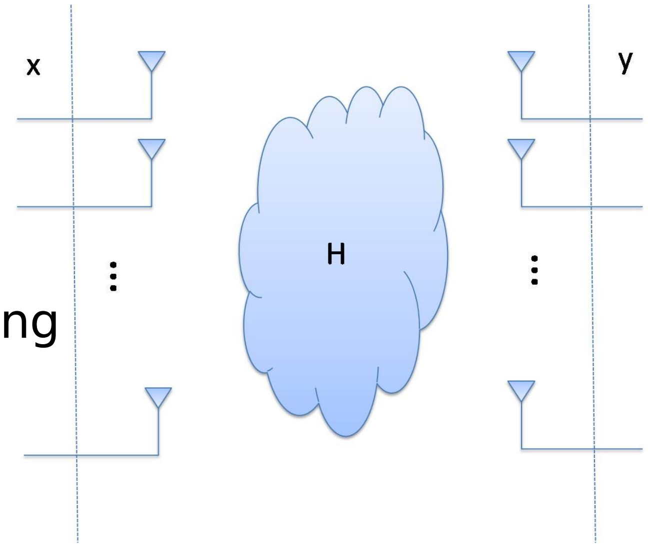
Motivation behind Cooperative Communications

Looking back at the MIMO system:

Multiplexing: BLAST, precoding

Diversity: Space-time coding, beamforming



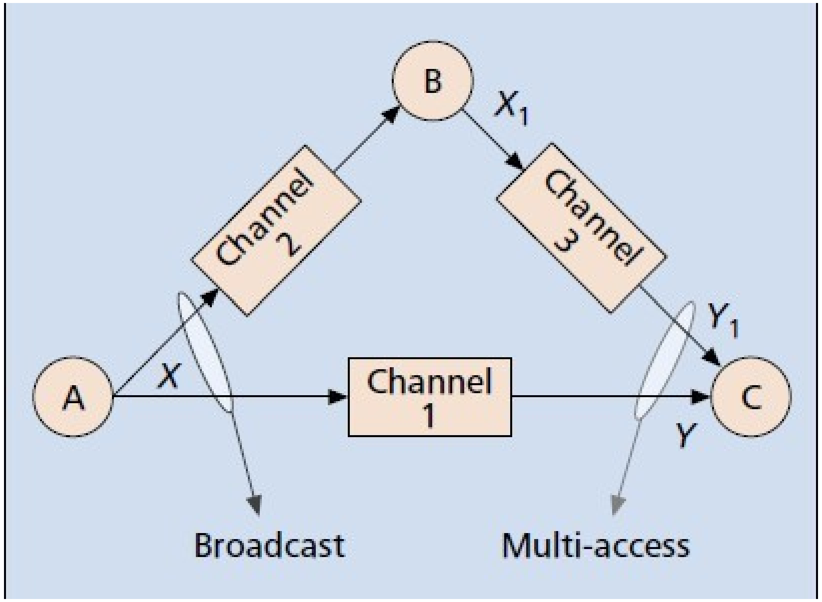
Can we get diversity gain without multi-antenna?

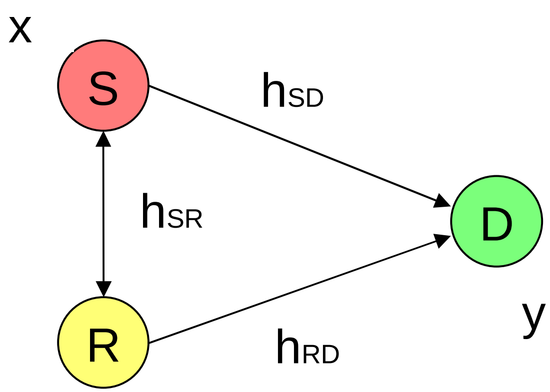
Cooperation Technique

Exploiting 2 fundamental aspects of wireless channels:

Broadcasting(Downlink)

Multiple Access(Uplink)





Relaying Technique:

A - Source - CoMp

B - Relay - Relay Cooperation

C - Destination - User Cooperation

Outline

Fundamental Cooperation Schemes

Cooperation in Cellular Networks

Future Work

Outline

<u>Fundamental Cooperation Schemes: AF and DF</u>

Cooperation in Cellular Networks

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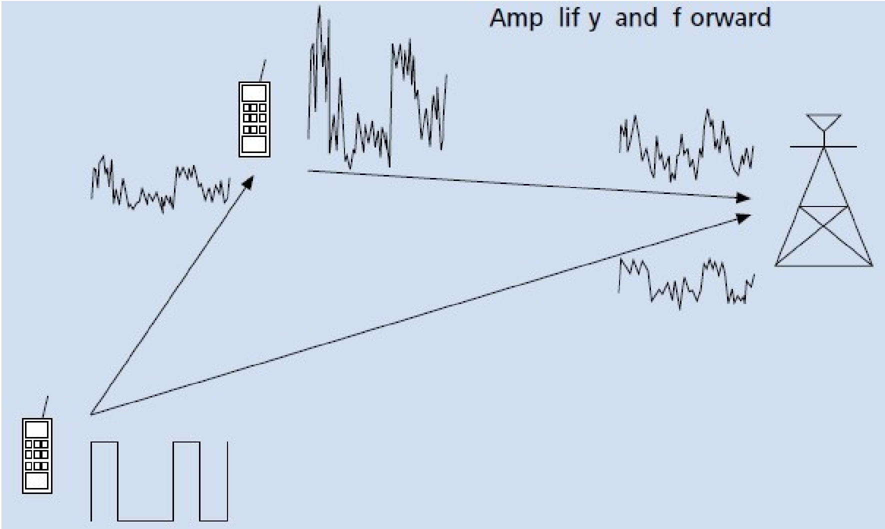
Fundamental Cooperation Schemes: Amplify-and-Forward

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{sd} \\ \sqrt{\alpha} h_{rd} h_{sr} \end{bmatrix} x + \begin{bmatrix} n_{sd} \\ \sqrt{\alpha} h_{rd} n_{sr} + n_{rd} \end{bmatrix}$$



Relay power constraint: $\alpha \le \frac{P_r}{|h_{sr}|^2 P_s + N_0}$

Sum rate:

$$I_{AF} = \log(1 + |h_{sd}|^2 SNR_{sd} + \frac{|h_{sr}|^2 |h_{rd}|^2 SNR_{sr} SNR_{rd}}{|h_{sr}|^2 SNR_{sr} + |h_{rd}|^2 SNR_{rd}})$$

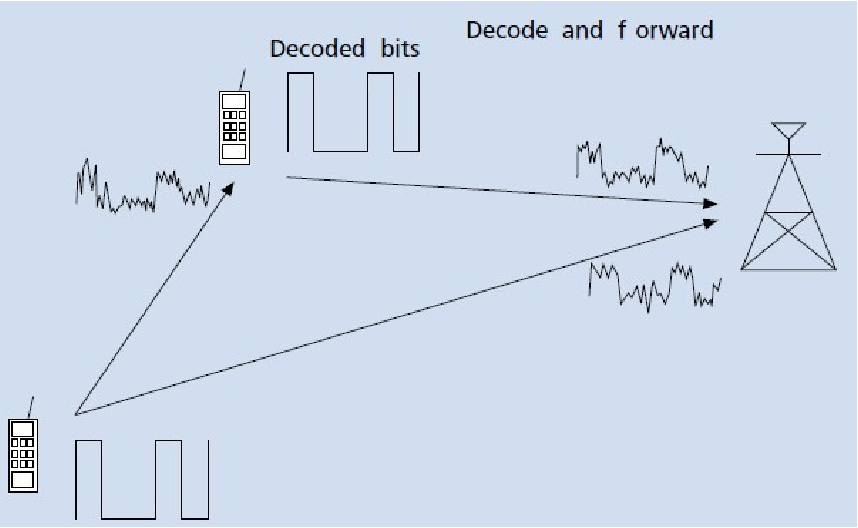
Relay: amplify and retransmit the noise version of the signal

Destination: Combine 2 independently faded versions of signals

Two-user case: diversity order=2

Fundamental Cooperation Schemes: Decode-and-Forward

$$x_r = \hat{x} \quad y_d = h_{rd}\hat{x} + n_{rd}$$



A simple example of DF cooperative with CDMA

2 users, spreading codes $c_1(t)$ and $c_2(t)$

3 time slots

$$X_1(t) = [a_{11}b_1^{(1)}c_1(t),\, a_{12}b_1^{(2)}c_1(t),\, a_{13}b_1^{(2)}c_1(t) + a_{14}\hat{b}_2^{(2)}c_2(t)]$$

$$X_2(t) = [a_{21}b_2^{(1)}c_2(t), a_{22}b_2^{(2)}c_2(t),\, a_{23}\hat{b}_1^{(2)}c_1(t) + a_{24}b_2^{(2)}c_2(t)]$$

Simplisity and adaptability to channel conditions

$$I_{DF} = \min\{\log(1+SNR_{sr}), \log(1+SNR_{rd})\} + \log(1+SNR_{sd})(upper\ bound)$$

Diversity order=1

Fundamental Cooperation Schemes: Others

- Demodulation-and-forward
- Compress-and-forward
- Estimate-and-forward
- Coded Cooperation

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Fundamental Cooperation Schemes

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Fundamental Cooperation Schemes

Cooperation in Cellular Networks

- **Relay Cooperation: Single Relay, Multiple Relay**
- BS Cooperation(CoMp or network-MIMO)

Future Work

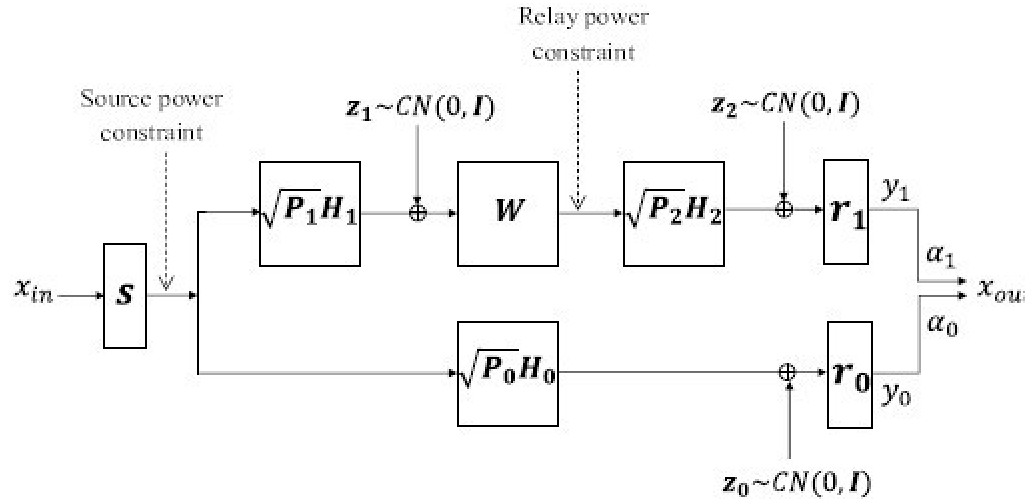
Single Relay Cooperation(classical MIMO-relay model)

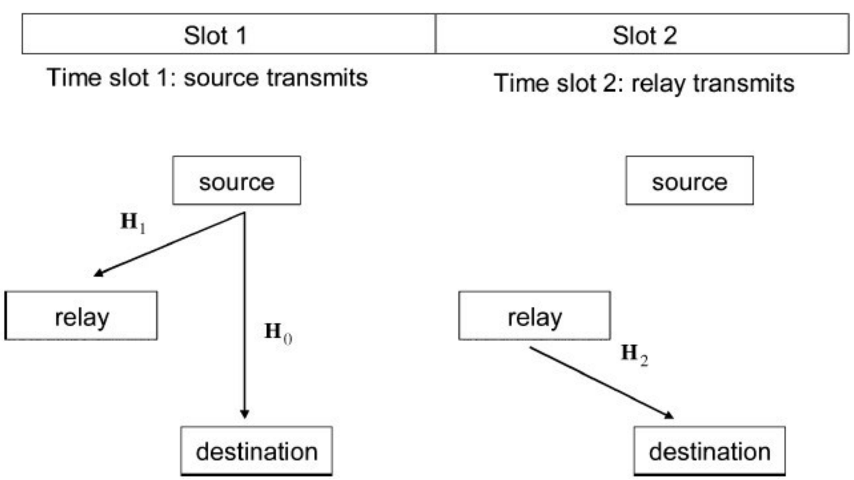
AF(non-regeneretive)-relay system

Transmitter: M antennas

Relay: K antennas

Receiver: N antennas

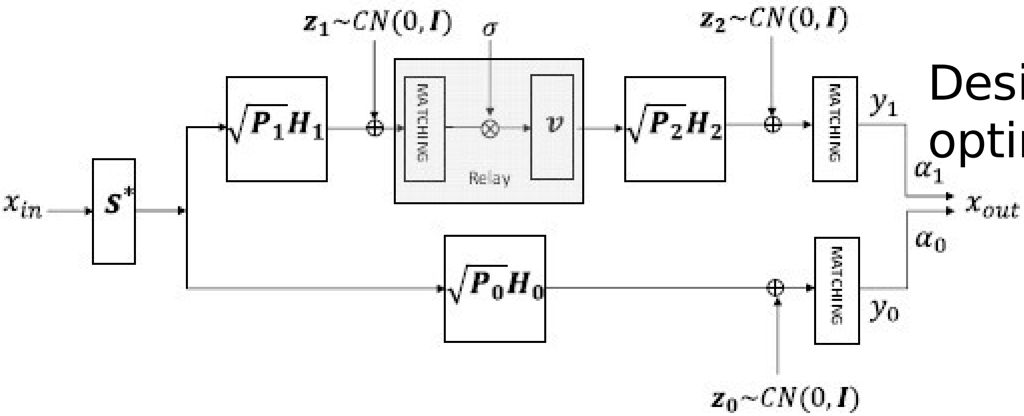




FDD system: full-duplex

TDD system: half-duplex: transmission and reception at relay using two orthogonal time slots

Single Relay Cooperation(classical MIMO-relay model)



Design Objective: Relay weighting matrix optimization to maximize the capacity

$$H_1 = U_1 \Sigma_1 V_1$$
$$H_2 = U_2 \Sigma_2 V_2$$

Absence of direct link: matching matrix $w = U_2 \Lambda_2 V_1$

MIMO-relay channel --> Paralled SISO-relay channel water-filling

With direct link: $$\gamma = \frac{P_1 P_2 \left| \mathbf{r}_1^H \mathbf{H}_2 \mathbf{W} \mathbf{H}_1 \mathbf{s} \right|^2}{P_2 \left\| \mathbf{W}^H \mathbf{H}_2^H \mathbf{r}_1 \right\|^2 + 1} + P_0 \| \mathbf{r}_0^H \mathbf{H}_0 \mathbf{s} \|^2$$

$$\max_{\mathbf{W}, \mathbf{s}, \mathbf{r}_0, \mathbf{r}_1} \quad \frac{P_1 P_2 \left| \mathbf{r}_1^H \mathbf{H}_2 \mathbf{W} \mathbf{H}_1 \mathbf{s} \right|^2}{P_2 \left\| \mathbf{W}^H \mathbf{H}_2^H \mathbf{r}_1 \right\|^2 + 1} + P_0 \| \mathbf{r}_0^H \mathbf{H}_0 \mathbf{s} \|^2$$

$$\text{s.t.} \quad \begin{cases} \|\mathbf{s}\| = \|\mathbf{r}_0\| = \|\mathbf{r}_1\| = 1 \\ P_1 \|\mathbf{W}\mathbf{H}_1\mathbf{s}\|^2 + \|\mathbf{W}\|_F^2 = 1 \\ \mathbf{W} \in \mathbb{C}^{n \times n}, \ \mathbf{s} \in \mathbb{C}^m, \ \mathbf{r}_0, \mathbf{r}_1 \in \mathbb{C}^l. \end{cases}$$

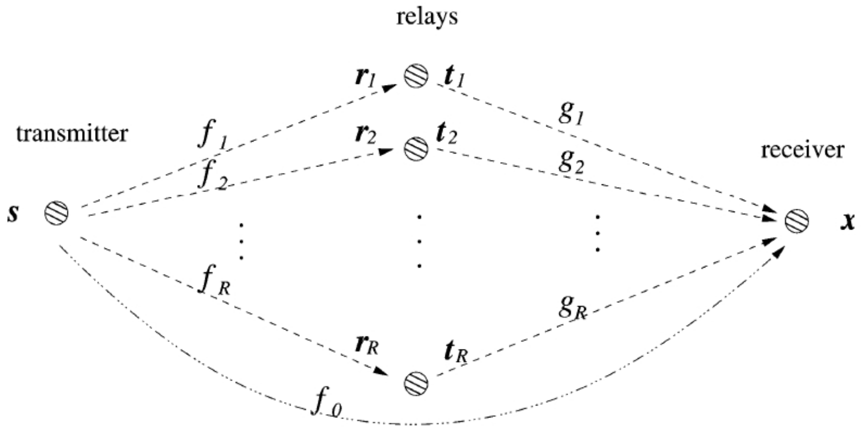
$$\mathbf{s}^\star = \arg \max_{\|\mathbf{s}\|=1} \frac{\|\mathbf{H}_1 \mathbf{s}\|^2}{\|\mathbf{H}_1 \mathbf{s}\|^2 + \lambda} + \mu \|\mathbf{H}_0 \mathbf{s}\|^2$$

$$\mathbf{W}^\star = \sigma \mathbf{v} \mathbf{u}^H$$

where $\mathbf{u} = \mathbf{H}_1 \mathbf{s}^\star / \|\mathbf{H}_1 \mathbf{s}^\star\|$, $\mathbf{v} = \mathbf{H}_2^H \mathbf{r}_1^\star / \|\mathbf{H}_2^H \mathbf{r}_1^\star\|$, and $\sigma = \left(1 + P_1 \|\mathbf{H}_1 \mathbf{s}^\star\|^2\right)^{-\frac{1}{2}}$.

More pratical implimentation: Limited Feedback

Multiple Relay Cooperation: Distributed Beamforming



This is a classical virtual-MIMO or distributed-MIMO model

transmitter, relay, receiver: 1 antenna

Design objective: Channel optimization from end to end

Processing factor at relay(distributed beamfoming vector)
Beamformer at receiver(if with direct link)

For engineering, we can consider limited feedback technique

More pratical use in ad-hoc and wireless sensor networks

Multiple Relay Cooperation: Relay Selection

a simlified version of distributed beamforming

Major relay selection metrics: Diversity Order

Best relay selection: R

$$r = \arg \max_{i=1,2\ldots R} \frac{|f_i g_i|^2 P P_i}{1 + |f_i|^2 P + |g_i|^2 P_i}$$

Nearset Neighbor Selection: 1

$$r = \arg \max_{i=1,2\ldots R} \max\{P|f_i|^2, P_i|g_i|^2\}$$

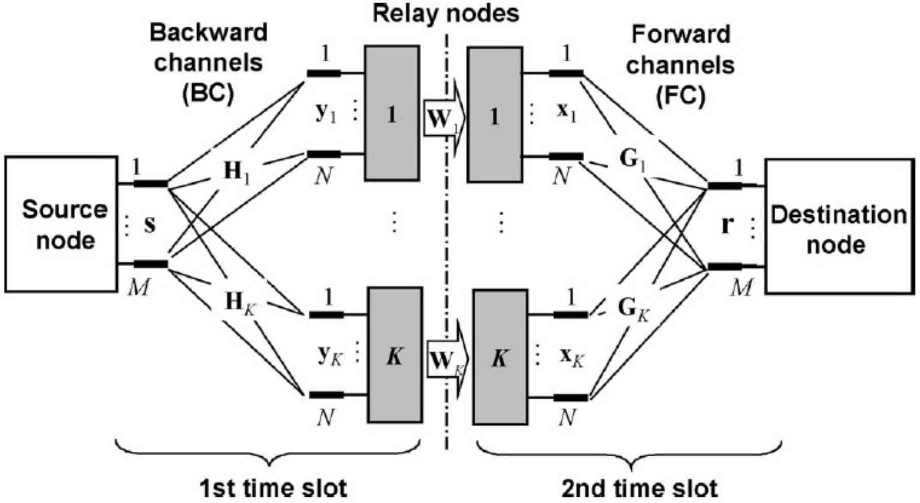
Best Worst Channel Selection: R

$$r = \arg \max_{i=1,2\ldots R} \min\{|f_i|, |g_i|\}$$

Best Harmonic Mean Selection: R

$$r = \arg \max_{i=1,2\ldots R} \max\left(\frac{1}{P|f_i|^2} + \frac{1}{P_i|g_i|^2}\right)^{-1}$$

Multiple Relay Cooperation: Multiple MIMO Relay Network



Transmitter: M antennas
Relay: K antennas
Receiver: N antennas

Coherent relay forward: transmiter and receiver channel information available at relay   Matching processing

$$C = \frac{M}{2}\log(K) + O(1), \quad K \to \infty$$

Non-coherent relay forward: transmiter and receiver channel information not available at relay   relay as a refrector

$$C = \frac{M}{2}\log(SNR) + O(1) \quad (SNR\ is\ high)$$

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Fundamental Cooperation Schemes

<u>Cooperation in Cellular Networks</u>

- Relay Cooperation: Single Relay, Multiple Relay
- **<u>BS Cooperation(CoMp or network-MIMO)</u>**

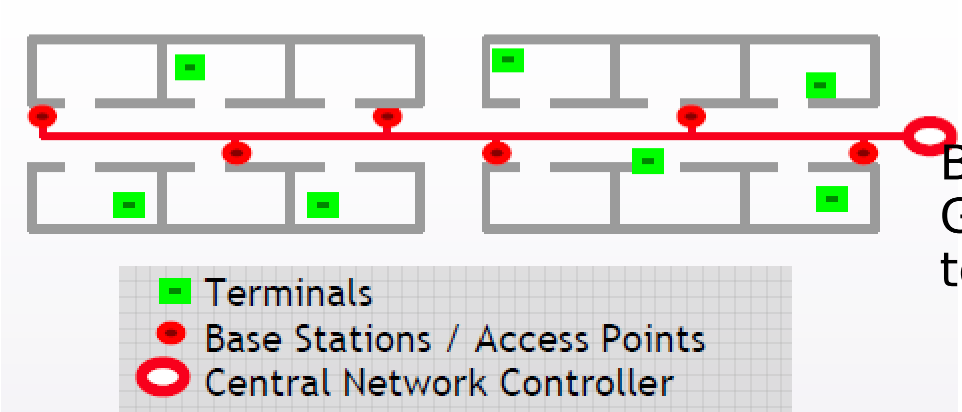
Future Work

BS Cooperation(CoMp or network-MIMO)

Bell Lab's Reseach Project: Network-MIMO(Coherently-Coodinated Base Stations

(http://www.youtube.com/results?search_query=network-MIMO&search_type=&ac

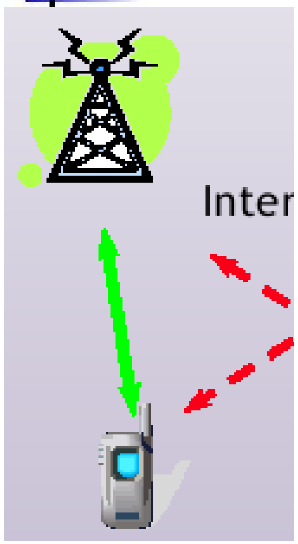
IEEE 802.16m Specification *(Document Number: IEEE C802.16m-08/346)*

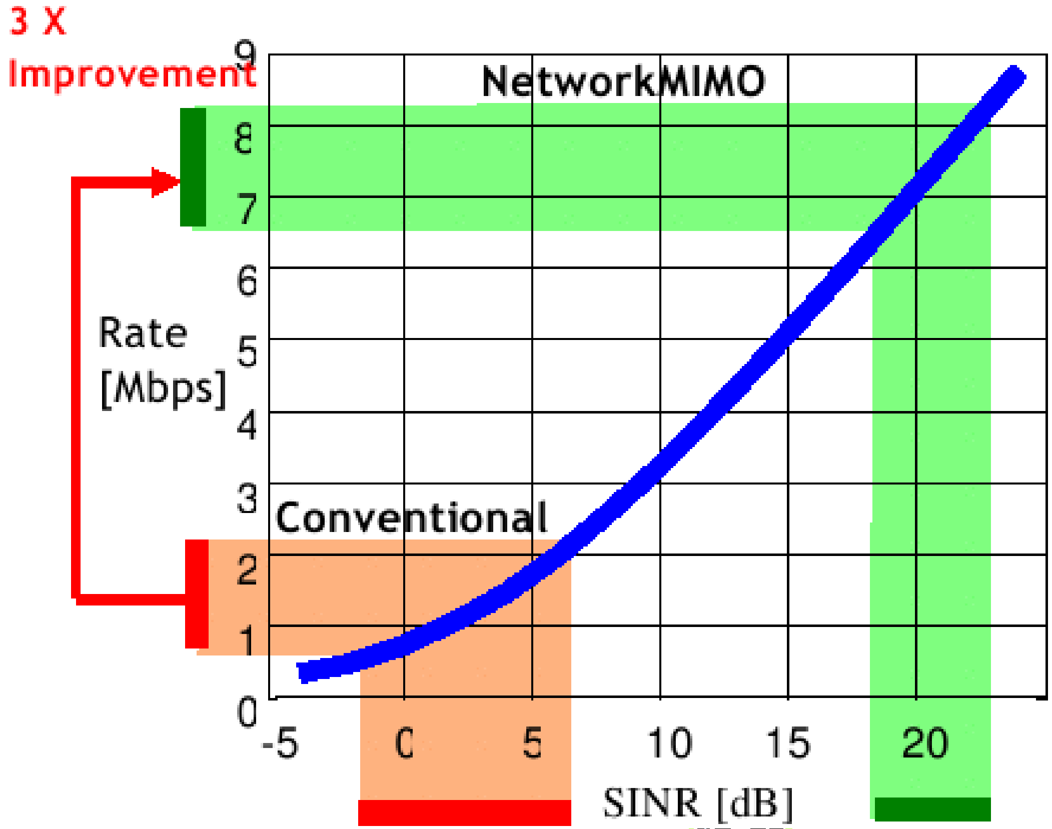


BS connection via a high-throughput Gigabit Ethernet backhaul network to the CNC

Overcoming inter-cell interference

BS Cooperation(CoMp or network-MIMO)



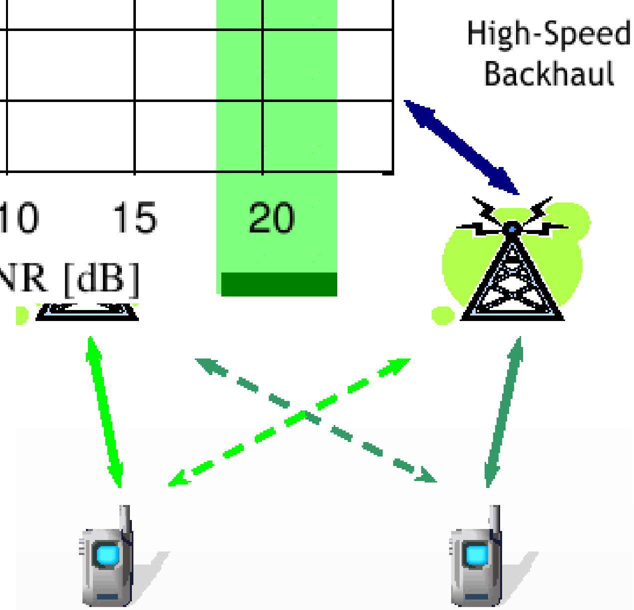


rk

the interference

Network-MI

All signals are useful, i.e. Interference is removed



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Fundamental Cooperation Schemes

Cooperation in Cellular Networks

Future Work

Future Work

Multiuser MIMO(LTE)
point-to-point relay(Advanced-LTE)
=>Multiuser MIMO-relay   Limited Feedback

Network-MIMO

Relay Cooperation   Two-way relay   Network Coding

Cooperation in ad-hoc and WSN

Cross-Layer Cooperation: Cooperative MAC
Cooperative hybrid ARQ
Cooprative Routing

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General

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Q&A

THANK YOU