Impact of transmitters desynchronization on the performance of cooperative MIMO systems

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Context

- Wireless Sensor Networks (WSN)
  - Energy consumption constraint
- Targeted applications
  - Monitoring (agriculture, health, …)
  - Military applications (zone surveillance, intrusion detection)
  - Intelligent Transportation System
- Cooperative MIMO technique in WSN
  - Energy efficient communications
  - Wide coverage

Presentation plan

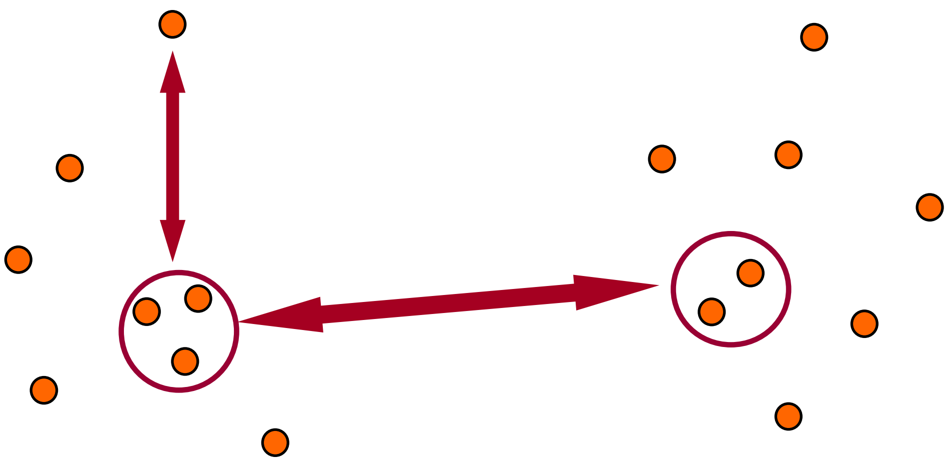
1. Introduction of cooperative MIMO technique
2. Impact of transmission synchronization error and cooperative reception techniques
3. New reception technique
4. Simulation results
5. Conclusion

Cooperative MIMO using STC for WSN

- MIMO space-time coding => Diversity gain
  - Reduces the error rate or transmission energy
- In WSN: Limited size or limited cost of each wireless sensor node
  - Each node can support only one antenna

=> Direct application of MIMO transmission technique is not practical

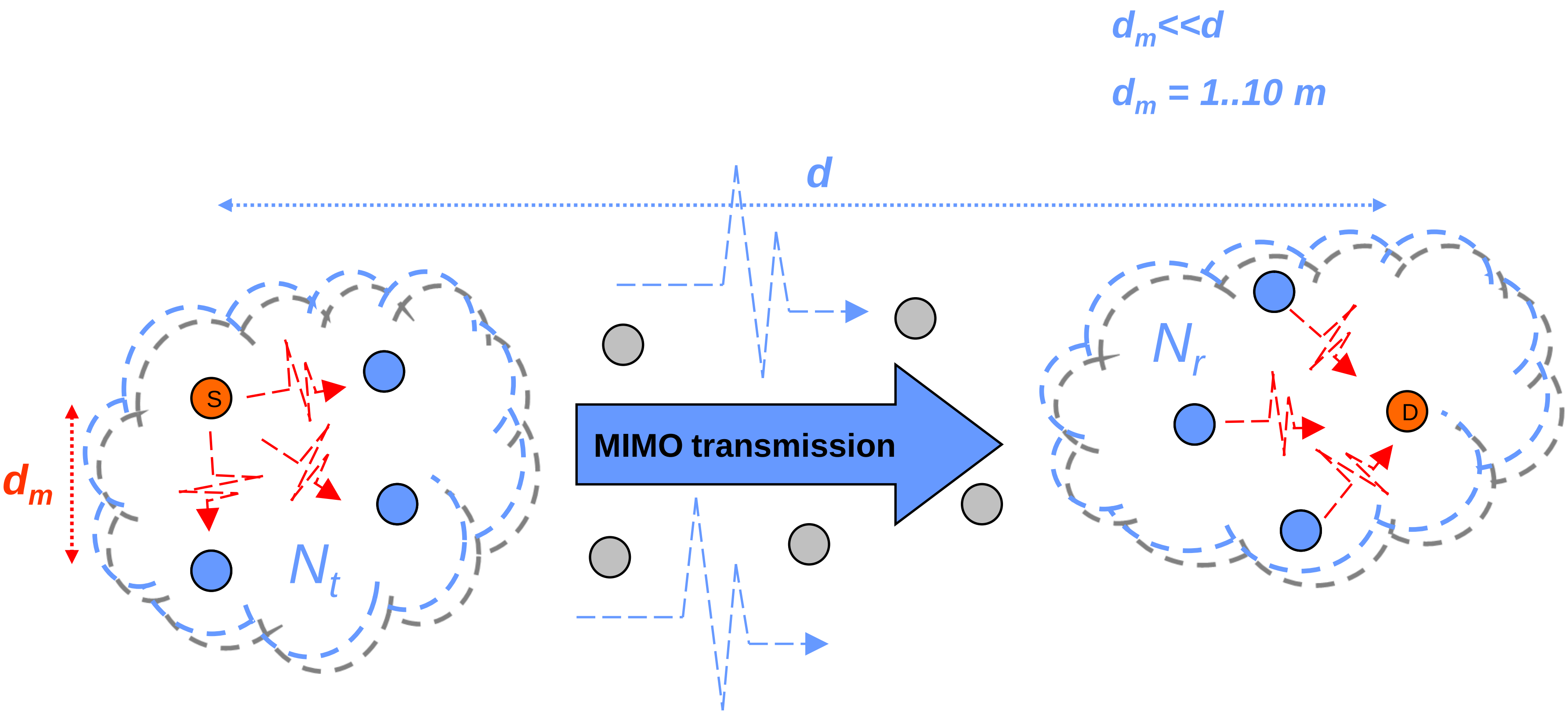
Individual nodes can cooperate → **Cooperative MIMO technique**



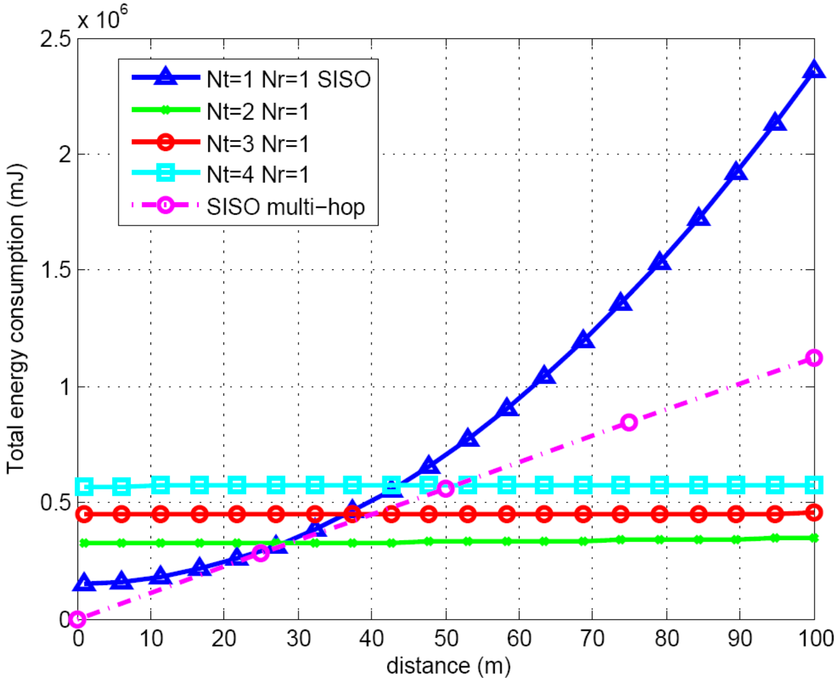
- Diversity gain of MIMO STBC
  - Energy efficiency of MIMO technique for long range transmission

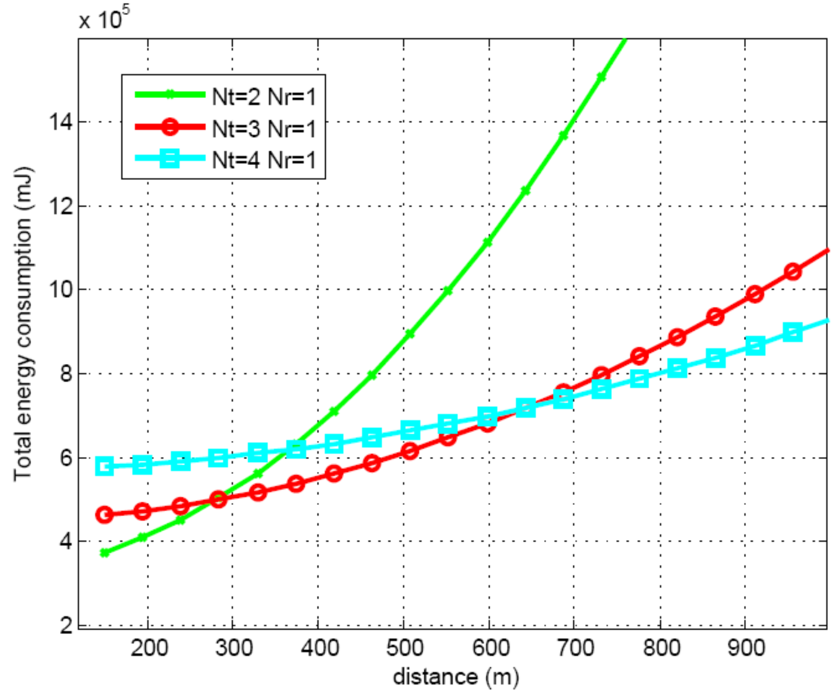
Cooperative MIMO technique

- Three phases of cooperative MIMO communications
  - Phase 1: Local data exchange
  - Phase 2: Cooperative MIMO transmission
  - Phase 3: Cooperative reception



Energy consumption of cooperative MIMO





- Cooperative MIMO technique is more energy efficient than SISO and multi-hop SISO techniques for long distance transmission [1,2]

[1] S. Cui, A. J. Goldsmith, and A. Bahai, "Energy-efficiency of MIMO and cooperative MIMO techniques in sensor networks," IEEE Jour. On Selected Areas in Communications, vol. 22, no. 6, pp. 1089 – 1098, August 2004.

[2] T. Nguyen, O. Berder, and O. Sentieys, "Cooperative MIMO schemes optimal selection for wireless sensor networks," IEEE 65th Vehicular Technology Conference, VTC-Spring, pp. 85–89, 2007.

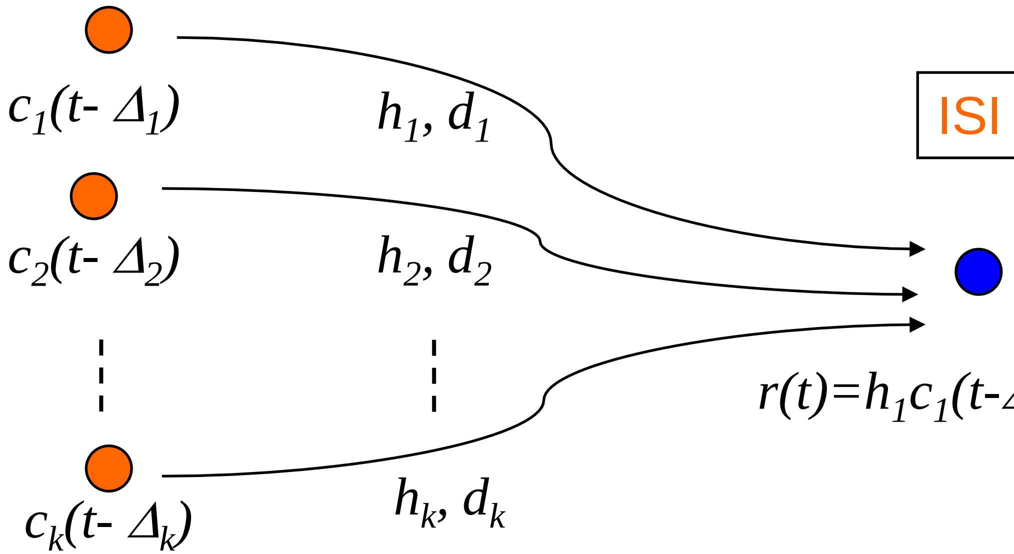
Cooperative MIMO disadvantages

- Transmission synchronization error
  - ISI, non-orthogonal space-time combination
- Additional noise of cooperative reception nodes
  - More noise in the final signal at the destination node

⇨ Performance degradation

⇨ Reduces the energy efficiency of cooperative MIMO over SISO

Transmitters desynchronization effect

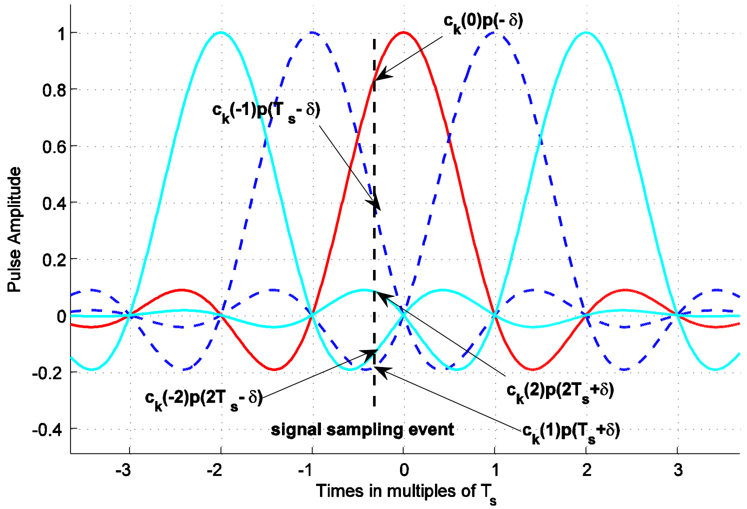


ISI from un-synchronized sequences

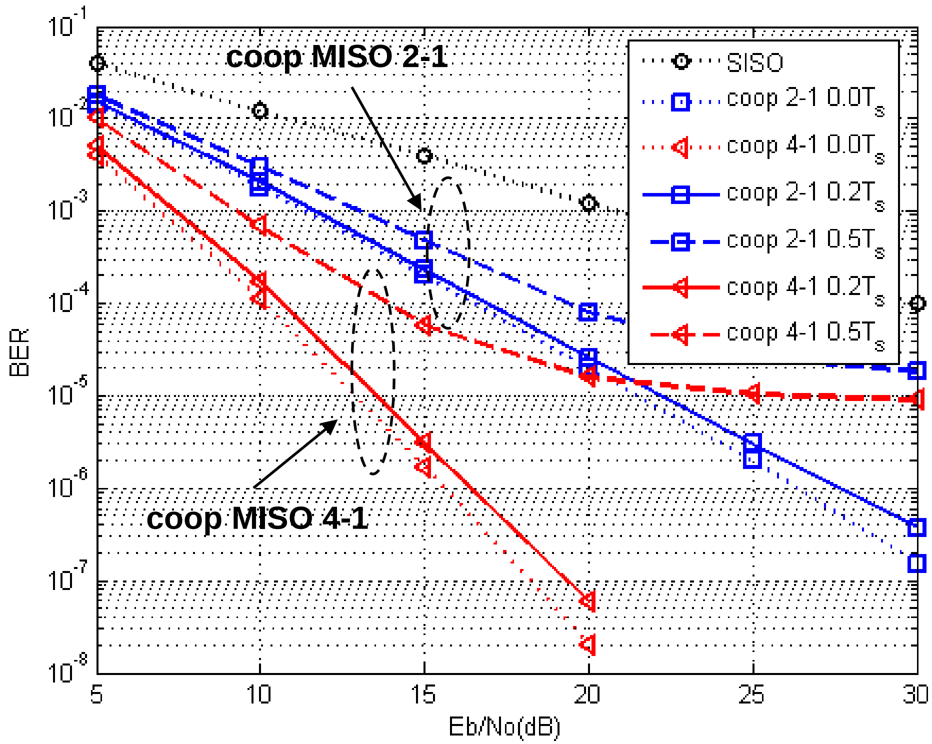
$$r(t)=h_1c_1(t-\Delta_1-d_1)+h_2c_2(t-\Delta_2-d_2)+\ldots+h_kc_k(t-\Delta_k-d_k)+n(t)$$

$$r(t)=\sum_{l=-\infty}^{\infty}\sum_{k=1}^{N_t}\alpha_k c_k[l]p(t-lT_s+\delta_k)+n(t)$$

$\delta_k=\Delta_k+d_k-\Delta_1-d_1$, for $k=1\ldots N_t$
is defined as the transmission synchronization error



Transmitters desynchronization effect



BER = 10^{-4}, $\Delta T_{syn} = 0.5T_s$

=> 3dB and 4dB of loss

- Degradation depends on the number of transmission nodes and desynchronization range.
- Cooperative performance is tolerant for small range of synchronization error
- Performance degradation is significant when the error range ΔT_{syn} is greater than $0.5T_s$

[3] T. Nguyen, O. Berder, and O. Sentieys, "Impact of transmission synchronization error and cooperative reception techniques on the performance of cooperative MIMO systems ", ICC 2008, Beijing, China

Non orthogonal space-time combination

- Two cooperative transmission nodes using Alamouti space time codes
- s_1 and s_2 are two symbols in one Alamouti block
- p(t): raised cosine pulse shape

$$\tilde{s_1} = \alpha_1^* r_1[1] + \alpha_2 r_1^*[2] = \boxed{(||\alpha_1||^2 + ||\alpha_2||^2 p(-\delta_2))s_1}$$
$$+\boxed{\alpha_1^* \alpha_2 (1 - p(-\delta_2))s_2} + \alpha_1^*(ISI_1^1 + n_1) + \alpha_2(ISI_2^1 + n_2)^*$$
$$\tilde{s_2} = \alpha_2^* r_1[1] - \alpha_1 r_1^*[2] = \boxed{(||\alpha_1||^2 + ||\alpha_2||^2 p(-\delta_2))s_2}$$
$$+\boxed{\alpha_1 \alpha_2^* (1 - p(-\delta_2))s_1} + \alpha_2^*(ISI_1^1 + n_1) - \alpha_1(ISI_2^1 + n_2)^* \quad \textbf{(1)}$$

- Decrease of the desired symbol amplitude
- Interferences between s_1 and s_2
  - Non-orthogonal space time combination

-> Performance degradation

Quantization Reception Technique

- Cooperative nodes retransmit their signals sequentially to the destination node for space-time combination

-> More additional noise from cooperative reception nodes in the final signal at the destination node.

-> Performance degradation

- Cooperative reception technique [1][2] -> "Symbol to bit quantization" and bits retransmission -> non efficient in transmission delay and in energy consumption

Forward reception techniques

- 2 proposed techniques employ "Amplify and forward"
  - Forward and Combine
  - Combine and Forward

1. Forward and combine

Received signal → Amplify and Forward → Space-time combination

(At the destination node)

2. Combine and forward

Received signal → Space-time combination → Amplify and Forward

(At each cooperative node)

Additional noise of reception techniques

- Forward and combine

$$\tilde{s_1} = \sum_{j=1}^{N_r}(||\alpha_{j,1}||^2 + ||\alpha_{j,2}||^2)s_1 + \sum_{j=1}^{N_r}(\alpha_{j,1}^* n_{1\,eff}^j + \alpha_{j,2} n_2^{j*}{}_{eff})$$

$$\tilde{s_2} = \sum_{j=1}^{N_r}(||\alpha_{j,1}||^2 + ||\alpha_{j,2}||^2)s_2 + \sum_{j=1}^{N_r}(\alpha_{j,2}^* n_{1\,eff}^j - \alpha_{j,1} n_2^{j*}{}_{eff})$$

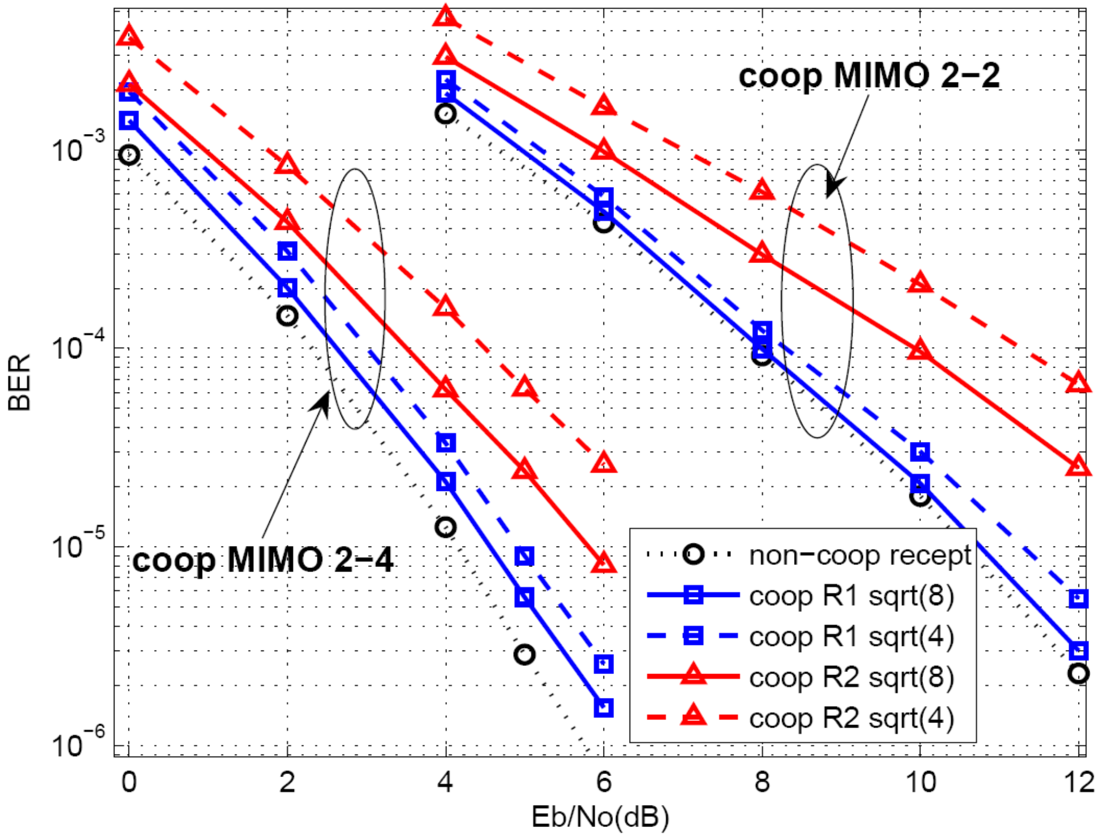
$$n_{i\,eff}^j = n_i^j + n_i'^j/K_1 \text{ with } i = 1,2 \qquad (2)$$

- Combine and forward

$$\tilde{s_1} = \sum_{j=1}^{N_r}(||\alpha_{j,1}||^2 + ||\alpha_{j,2}||^2)s_1 + \sum_{j=1}^{N_r}(\alpha_{j,1}^* n_1^j + \alpha_{j,2} n_2^{j*} + n_1'^j/K_2)$$

$$\tilde{s_2} = \sum_{j=1}^{N_r}(||\alpha_{j,1}||^2 + ||\alpha_{j,2}||^2)s_2 + \sum_{j=1}^{N_r}(\alpha_{j,2}^* n_1^j - \alpha_{j,1} n_2^{j*} + n_2'^j/K_2) \qquad (3)$$

Impact of reception techniques



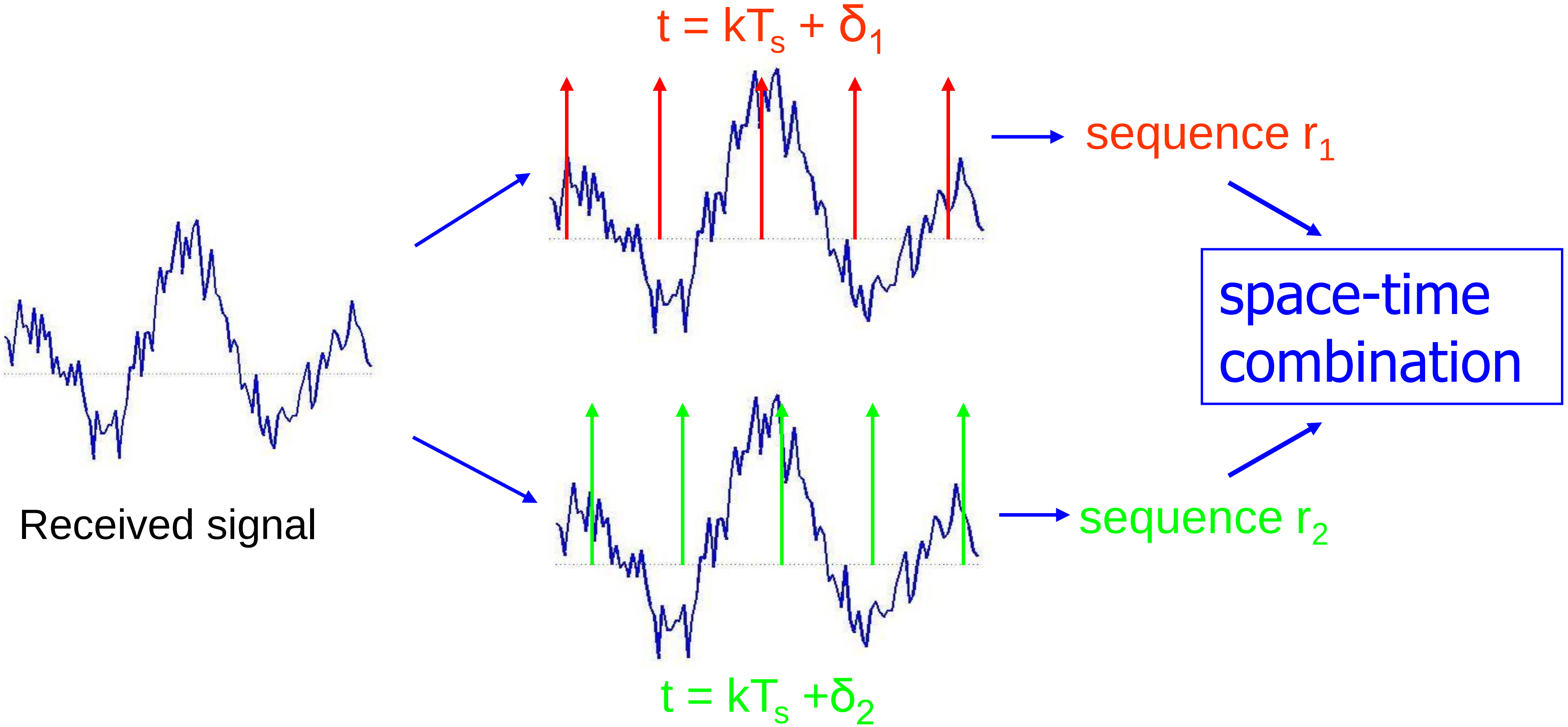
coop R1 sqrt(4) -> Forward and Combine technique with amplification factor K1 = 2

coop R2 sqrt(8) -> Combine and Forward technique with amplification factor K2 = 2√2

- Performance degradation depends on number of cooperative reception nodes and amplification factor K
- Forward and Combine technique is better than Combine and Forward technique

New space-time combination technique

- Two delayed sampling processes
- Space-time combination from two sampled sequences



New space-time combination technique

$$\tilde{s_1} = \alpha_1^* r_1[1] + \alpha_2 r_2^*[2] = ||\alpha_1||^2 s_1 + \alpha_1^* \alpha_2 s_2 p(-\delta_2)$$
$$+\alpha_1^*(ISI_1^1 + n_1^1) - \alpha_1^* \alpha_2 s_2 p(\delta_2) + ||\alpha_2||^2 s_1 + \alpha_2(ISI_2^2 + n_2^2)^*$$
$$= \boxed{(||\alpha_1||^2 + ||\alpha_2||^2) s_1} + \alpha_1^*(ISI_1^1 + n_1^1) + \alpha_2(ISI_2^2 + n_2^2)^*$$
$$\tilde{s_2} = \alpha_2^* r_2[1] - \alpha_1 r_1^*[2] = \alpha_1 \alpha_2^* s_1 p(-\delta_2) + \alpha_2^*(ISI_1^2 + n_1^2)$$
$$+||\alpha_2||^2 s_2 + ||\alpha_1||^2 s_2 - \alpha_1 \alpha_2^* s_1 p(\delta_2) - \alpha_1(ISI_2^1 + n_2^1)^*$$
$$= \boxed{(||\alpha_1||^2 + ||\alpha_2||^2) s_2} + \alpha_2^*(ISI_1^2 + n_1^2) - \alpha_1(ISI_2^1 + n_2^1)^* \quad \textbf{(2)}$$

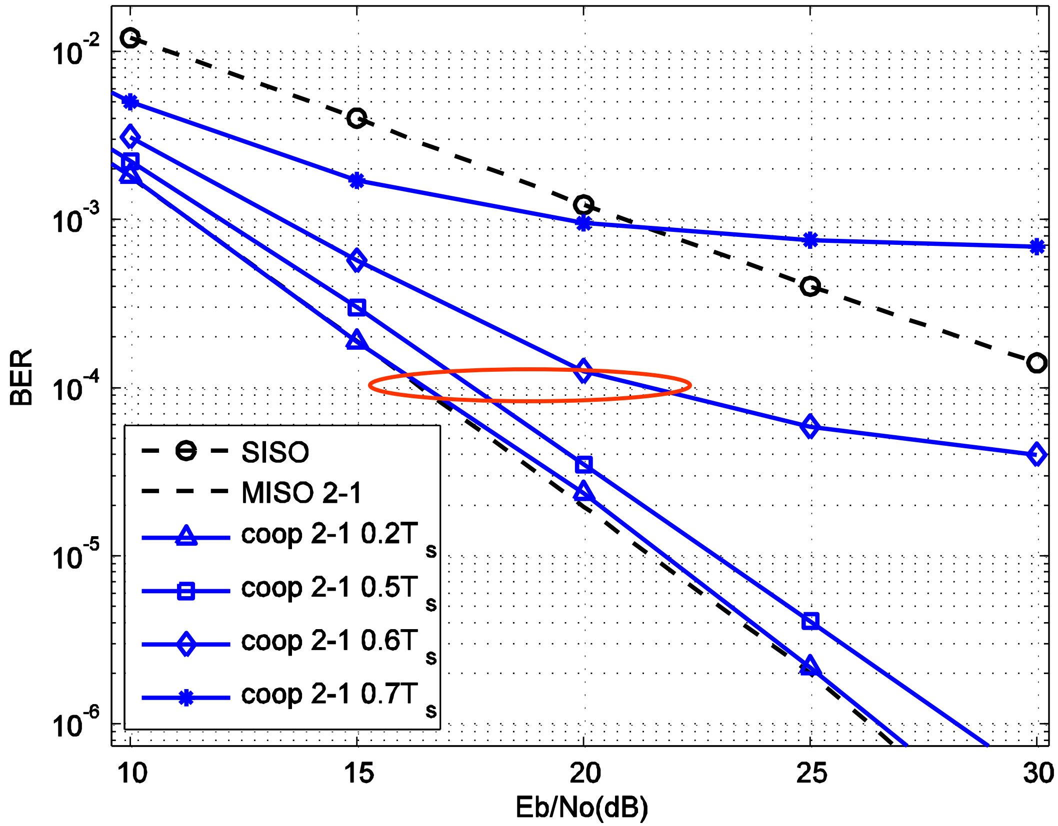
- Advantages of new combination technique
  - The amplitude of the desired symbols does not decrease
  - Reconstructs the space-time orthogonal combination

Simulation results

- MISO (2-1) using Alamouti space-time codes
- Rayleigh flat fading channel (independent fading between 2 frames of 120 symbols QPSK)
- ECC is not included
- Transmission synchronization error is uniformly distributed in $\left[-\Delta T_{syn}/2, +\Delta T_{syn}/2\right]$ with the error range ΔT_{syn}

[4] T. Nguyen, O. Berder, and O. Sentieys, "Efficient space time combination technique for unsynchronized cooperative MISO transmission", IEEE 67th Vehicular Technology Conference, VTC-Spring 2008, Singapore

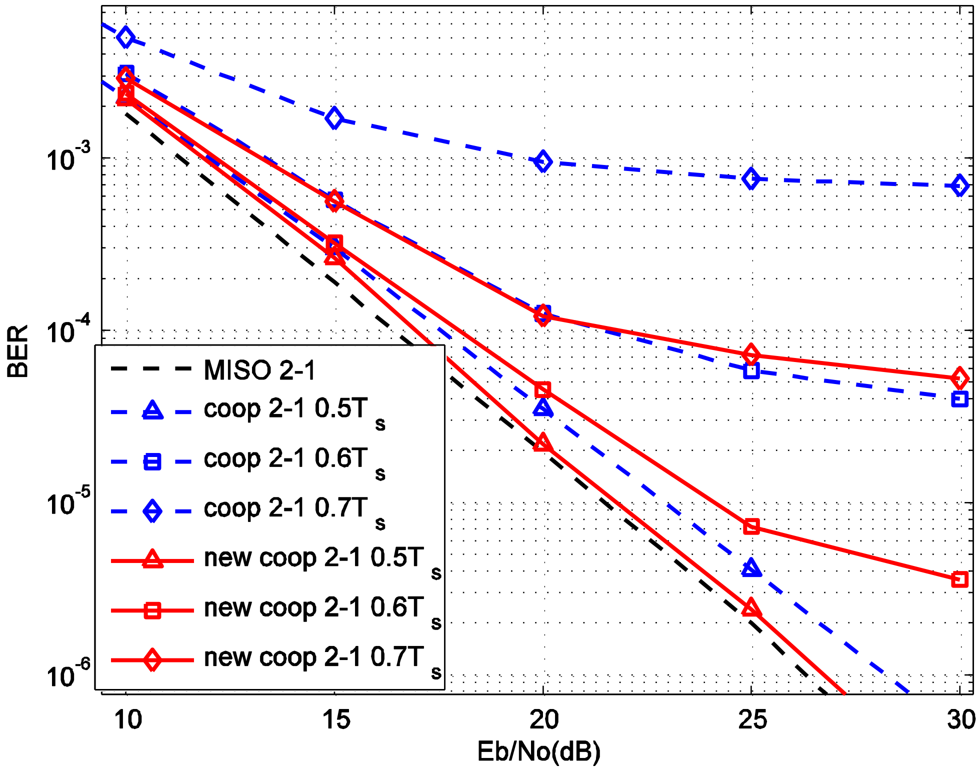
Effect of transmitters desynchronization



BER = 10^{-4}, $\Delta T_{syn} = 0.6T_s$
5dB loss

- Performance degradation is significant when the error range ΔT_{syn} is greater than $0.5T_s$

BER performance



BER = *10*$^{-5}$, $\Delta T_{syn} = 0.5T_s$
1dB gain

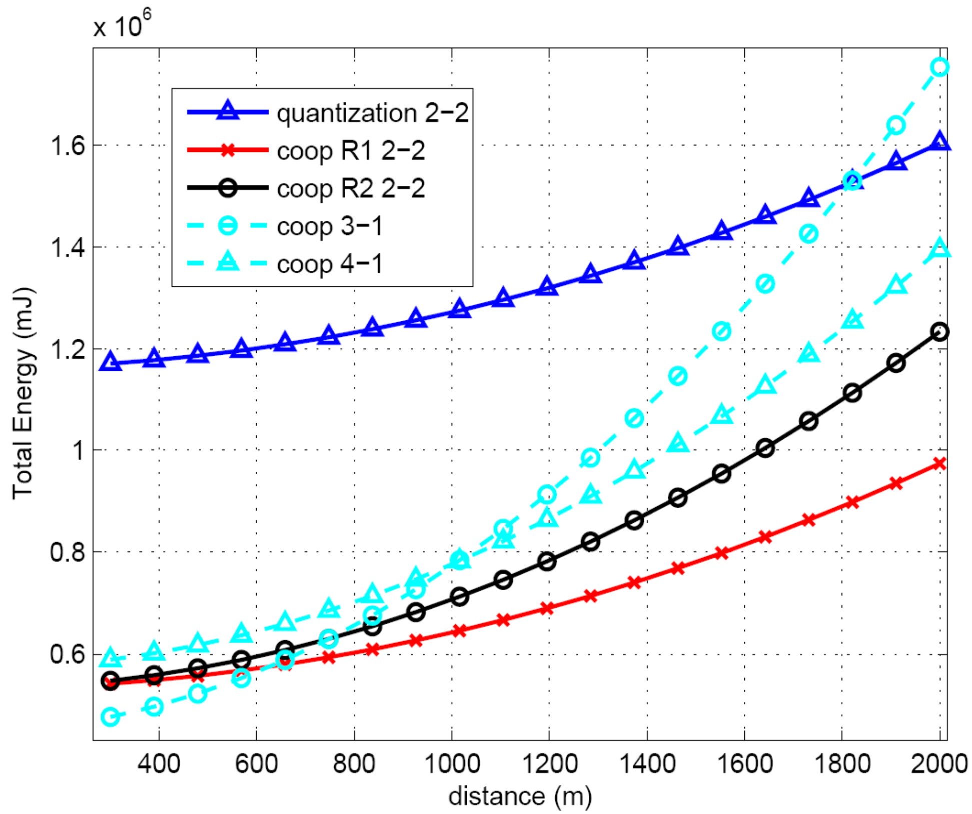
BER = *10*$^{-4}$, $\Delta T_{syn} = 0.6T_s$
4dB gain

- New proposed combination technique has a better performance than the traditional combination in the presence of transmission synchronization errors

Conclusion and future works

- Impact of transmission synchronization error
  - Degradation depends on synchronization error range
  - Cooperative MIMO system is tolerant for small synchronization error range
- Impact of cooperative reception technique
  - Degradation depends on number of cooperative nodes
  - The combine-forward and forward-combine techniques are more efficient than the quantization technique
- New efficient space-time combination
  - Simple combination algorithm
  - Better performance than the traditional combination technique
  - Demands less precise synchronization process
- Future works
  - Optimize amplifying factors for cooperative reception techniques
  - Derive for 3 and 4 cooperative transmission nodes
  - Compare to relay techniques and delay-tolerant space-time block codes

Thanks for your attention !!!



- The proposed cooperative reception techniques (coop R1 and coop R2) are better than the previous cooperative reception technique (quantization) in energy consumption

Simulation results

- Cooperative MIMO systems using Alamouti (2 transmission nodes) and Tarokh (3,4 transmission nodes) space-time codes.
- Rayleigh flat fading channel (independent fading between 2 frames of 120 QPSK symbols)
- AWGN channel for local cooperative transmission (phase 1 and 3)
- ECC is not included
- Transmission synchronization error is uniformly distributed in $\left[-\Delta T_{syn}/2, +\Delta T_{syn}/2\right]$ with the error range ΔT_{syn}
- *Inter-symbol interference from 4 nearest symbols*