Energy-efficient Wireless Sensor Networks with Cooperative MIMO Techniques

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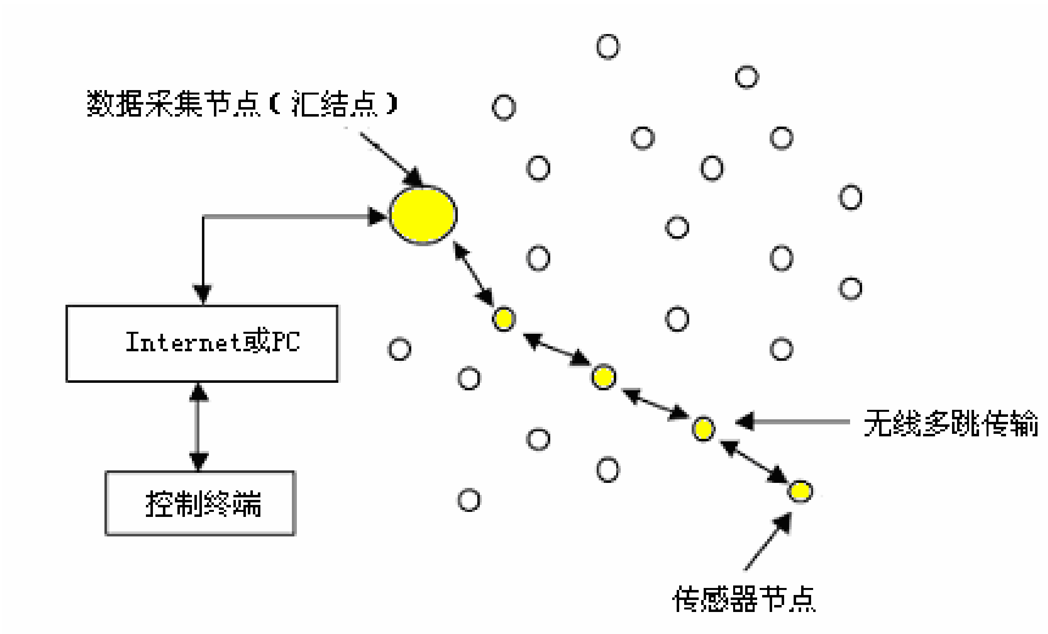
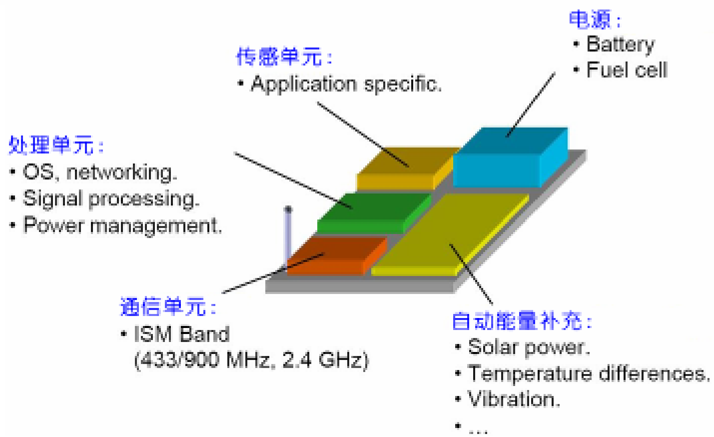
Outline

- Introduction and Related Work
- System Model
- Energy Analysis of Cooperative MIMO Communication with Data Aggregation
- Further Work

Wireless Sensor Networks



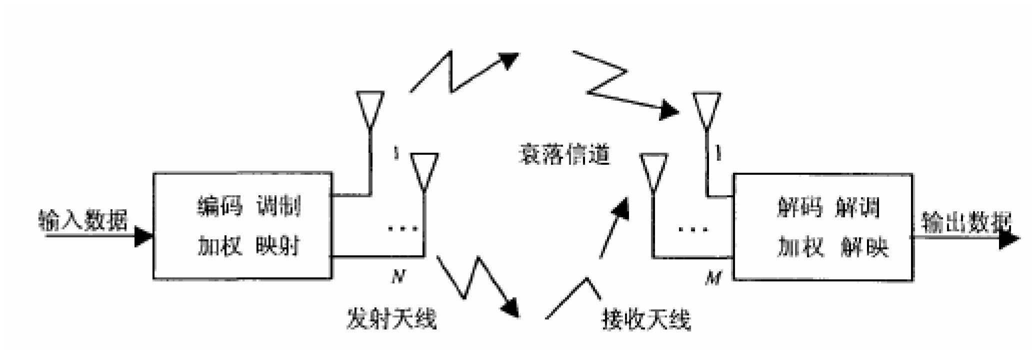


Characters:

- Special Ad-hoc Network
- No Base Station
- Multi-hop Network
- Data Traffic: Sensors->Sink
- Quasi-synchronized
- Highly Redundant Raw Data
- Strict Energy Constraints
- Low Price
- Easy to Deploy

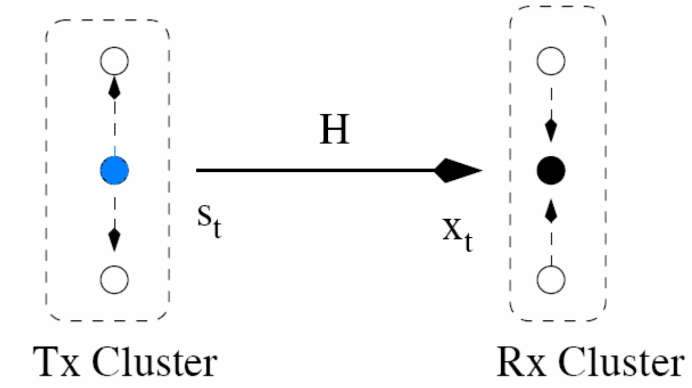
Cooperative MIMO

MIMO:



•Multiple Antenna in Transceivers

C-MIMO:



•Generally speaking, one Ant. for one sensor node

•Establish virtual Ant. Array in a cluster of sensor nodes

•Inner-cluster communication power for C-MIMO

ADVs.

•Under equivalent conditions, MIMO costs less power per bit than SISO.

•For long-haul transmission, C-MIMO costs less power per bit than SISO

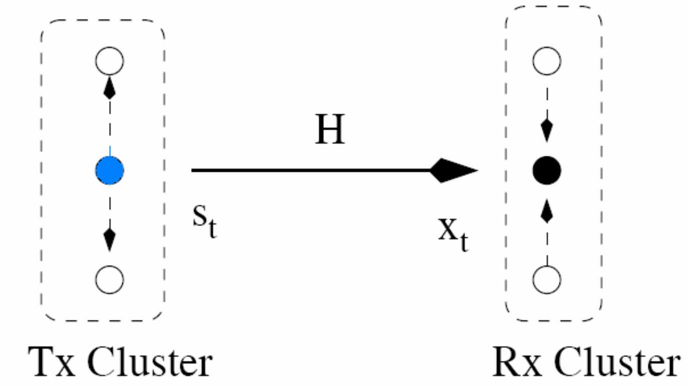
Cooperative MIMO

Analysis:

•Wisely exploiting MIMO technology to reduce the communication energy of WSN

•Clustering to form distributed ant. arrays

C-MIMO:



•Generally speaking, one Ant. for one sensor node
•Establish virtual Ant. Array in a cluster of sensor nodes
•Inner-cluster communication power for C-MIMO

Problems:

• How to form a cluster optimally?

• How to tradeoff between long-haul communication energy reduction and inner-cluster communication cost?

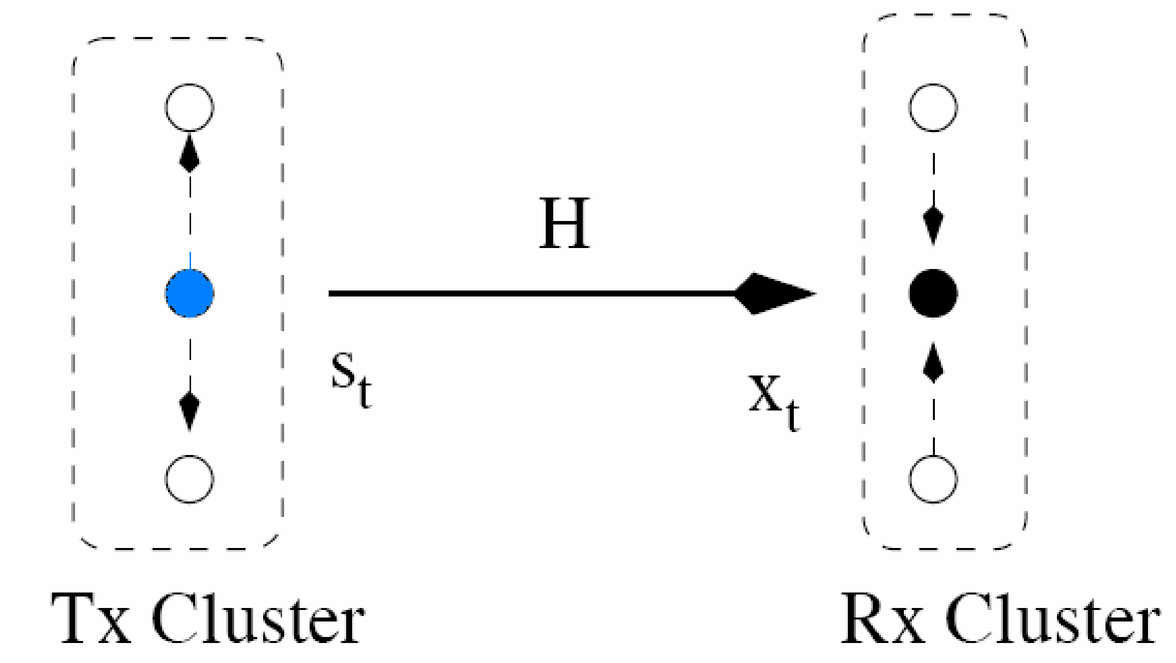
ADVs.

•Under equivalent conditions, MIMO costs less power per bit than SISO.

•For long-haul transmission, C-MIMO costs less power per bit than SISO

Cooperative MIMO for WSN

C-MIMO WSN:



- **Sensor nodes cooperates to form virtual arrays**
- **Extra Communication Energy Consumption**

Related Work

- **SISO**
- **Cooperative MIMO**
  - **Do not consider the data redundancy**
  - **Consider the data redundancy**

Cui and Goldsmith, 2004

- Point-to-point communication power model
- Categorize the power dissipation into circuit power and trans. power
- Optimize the power over modulation orders

Related Work

- **SISO**
- **Cooperative MIMO**
  - **Do not consider the data redundancy**
  - **Consider the data redundancy**

Cui and Goldsmith, 2004

- Establish C-MIMO power model for WSN
- Justifying C-MIMO application by showing its energy efficiency

Jayaweera, 2005

- Shows that although C-MIMO introduces extra power, it still reduces the overall power consumption for long-haul transmission

Related Work

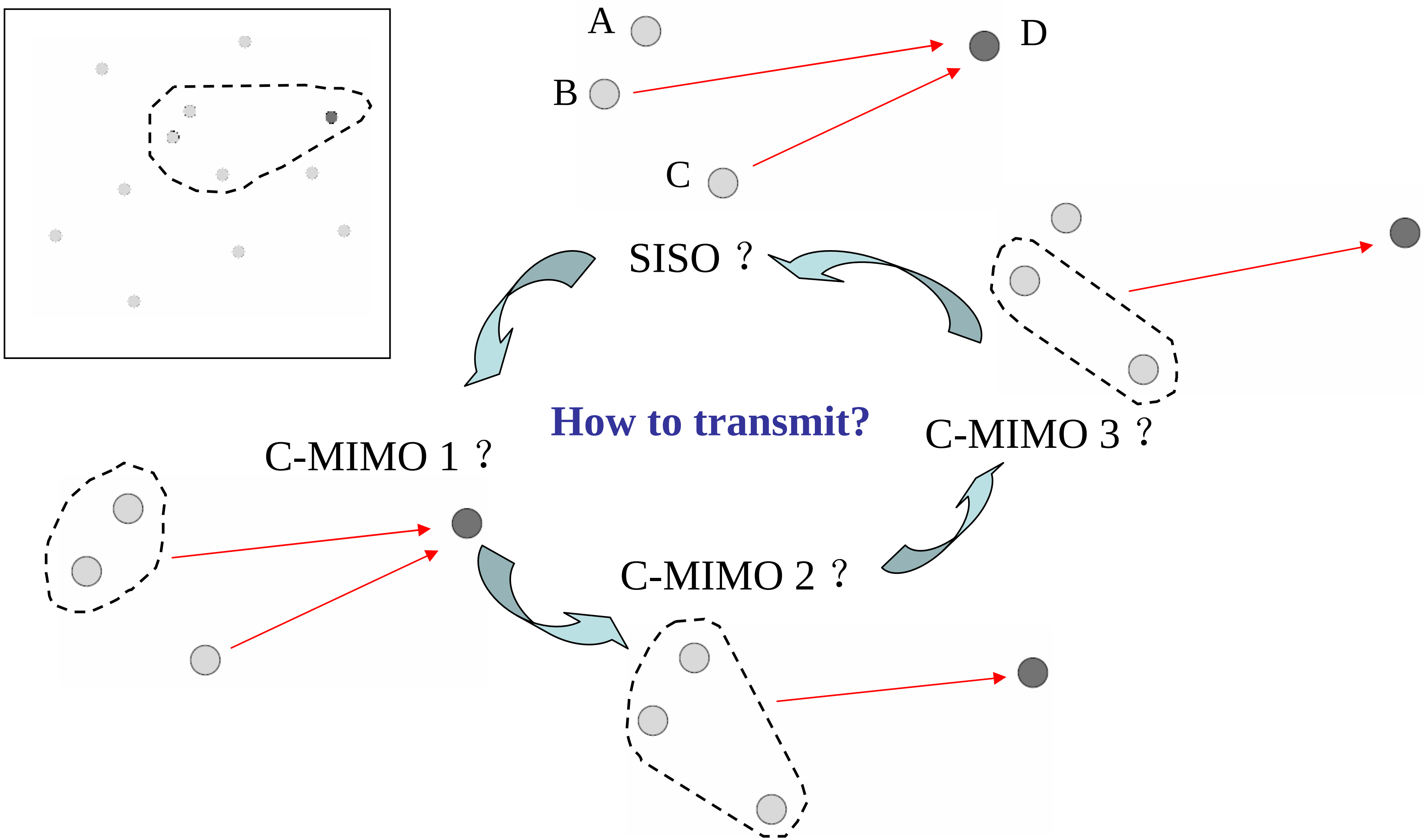
- **SISO**
- **Cooperative MIMO**
  - **Do not consider the data redundancy**
  - **Consider the data redundancy**

No apparent work done yet.

System Model

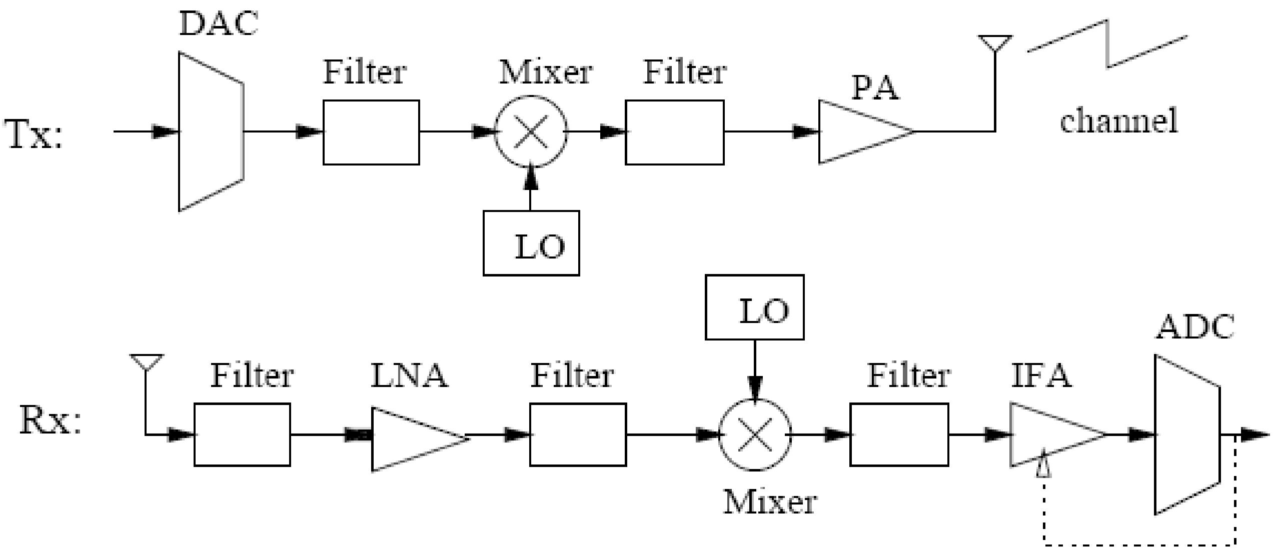
- Narrowband System
- Frequency-flat Rayleigh Fading Communication Channels
- Perfectly Synchronized Transmission/Reception
- Energy Consumption of Baseband Signal
- Processing Blocks Can Be Omitted
- Uncoded System
- Optimally Chosen Constellation Size
- M_T Transmit Antennas and M_R Receive Antennas
- Channel Matrix $\mathbf{H}$ is of Complex Fading Coefficients

C-MIMO Transmission Model



Basic Comm. Power Model

- Transceiver Models

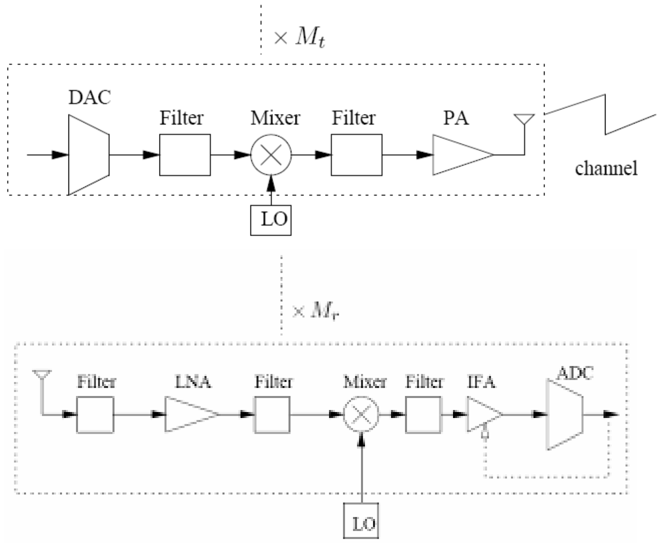


P_{syn}、P_{mix}、 P_{LNA}、 P_{IFA}、 P_{DAC}、 P_{ADC}、 P_{amp}、 $P_{filt}(Transmitting)$、 $P_{filr}(\mathrm{Re}\,ceiving)$

Overall Power： $E = P_{on}T_{on} + P_{tr}T_{tr} + P_{sp}T_{sp}$

C-MIMO Comm. Power Model

- M_t transmitting Ant. and M_r Receiving Ant.
- Fixed Modulation Order, transmission power is



$$P_t = P_{out} = \bar{E}_b R_b \times \frac{(4\pi)^2 d^2}{G_t G_r \lambda^2} M_l N_f$$

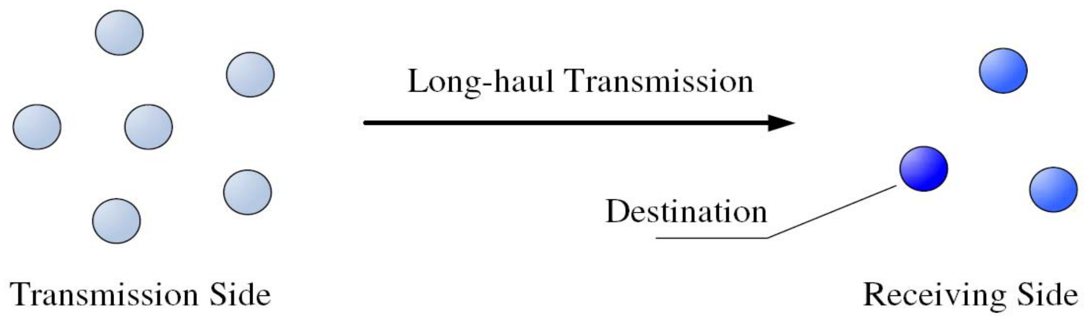
- Overall power consumption is：

$$P_c \approx M_t (P_{DAC} + P_{mix} + P_{filt}) + 2P_{syn} + M_r (P_{LNA} + P_{mix} + P_{IFA} + P_{filr} + P_{ADC})$$

- Power consumption per bit is： $E_{bt} = ((1+\alpha)P_{out} + P_c)/R_b$

- We have： $E_{bt} = (1+\alpha)\bar{E}_b \times \frac{(4\pi d)^2}{G_t G_r \lambda^2} M_l N_f + P_c T_{on} / L$

C-MIMO v.s. SISO



C-MIMO

Overall Power:

$$E_{MIMO} = \sum_{i=1}^{M_t} N_i E_i^t + E_b^r \sum_{i=1}^{M_t} N_i + \sum_{j=1}^{M_r-1} E_j^r n_r N_s$$

Overall Delay

$$T_{MIMO} = T_s \left(\sum_{i=1}^{M_t} \frac{N_i}{b_i^t} + \frac{\sum_{i=1}^{M_t} N_i}{b_m} + \sum_{j=1}^{M_r-1} \frac{n_r N_s}{b_j^r} \right)$$

SISO

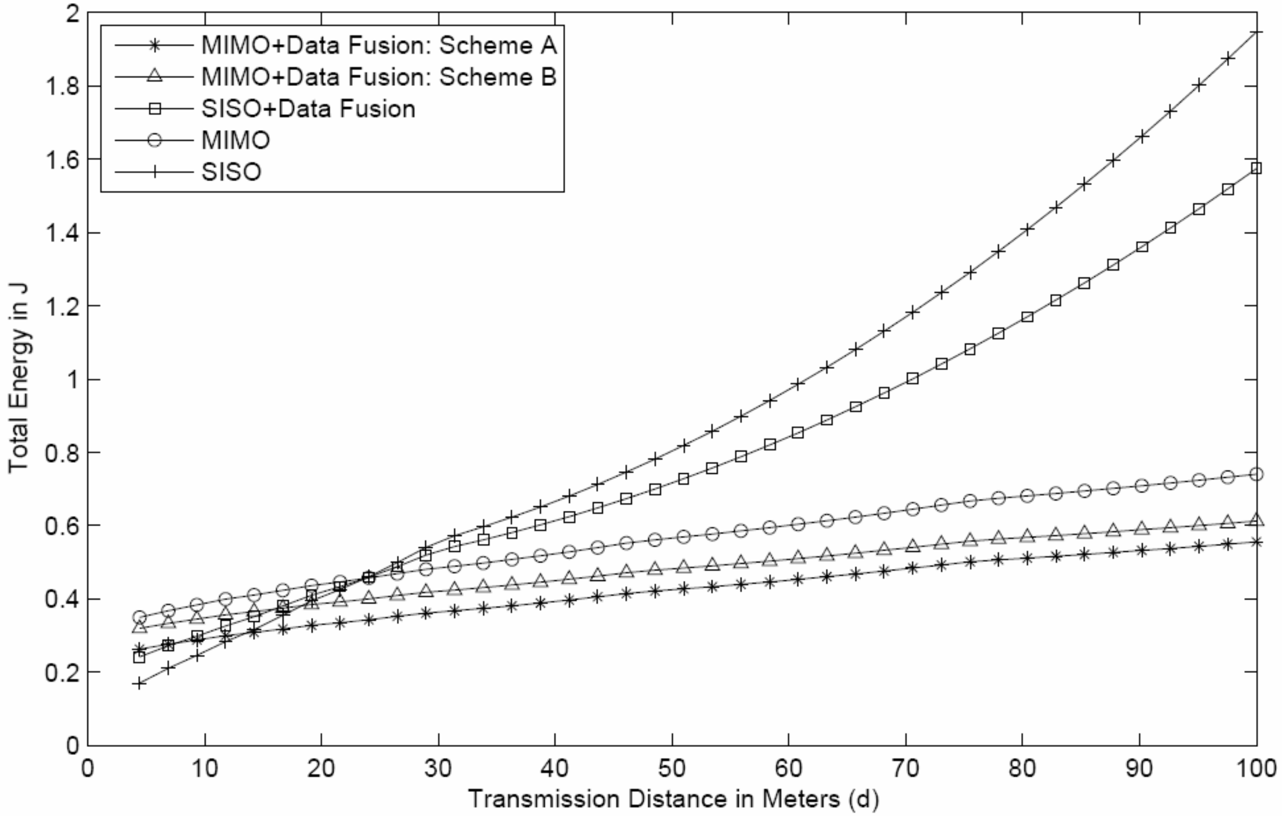
Overall Power

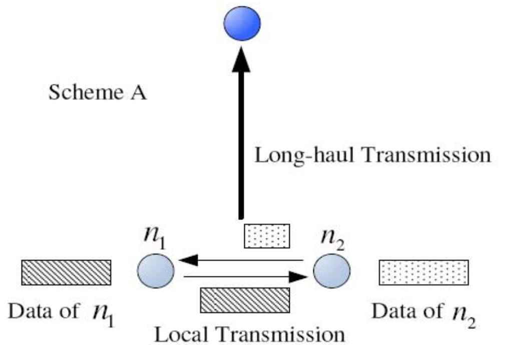
$$E_{SISO} = \sum_{i=1}^{M_t} N_i E_i^0$$

Overall Delay

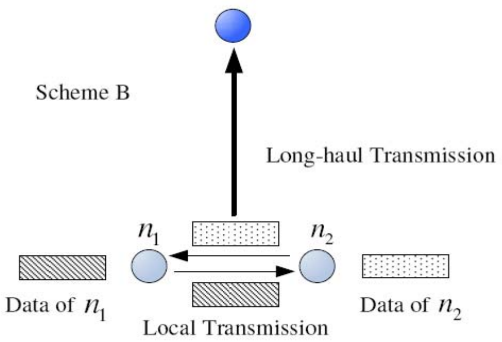
$$T_{SISO} = \sum_{i=1}^{M_t} \frac{N_i}{b_i^0} T_s$$

SISO v.s. C-MIMO



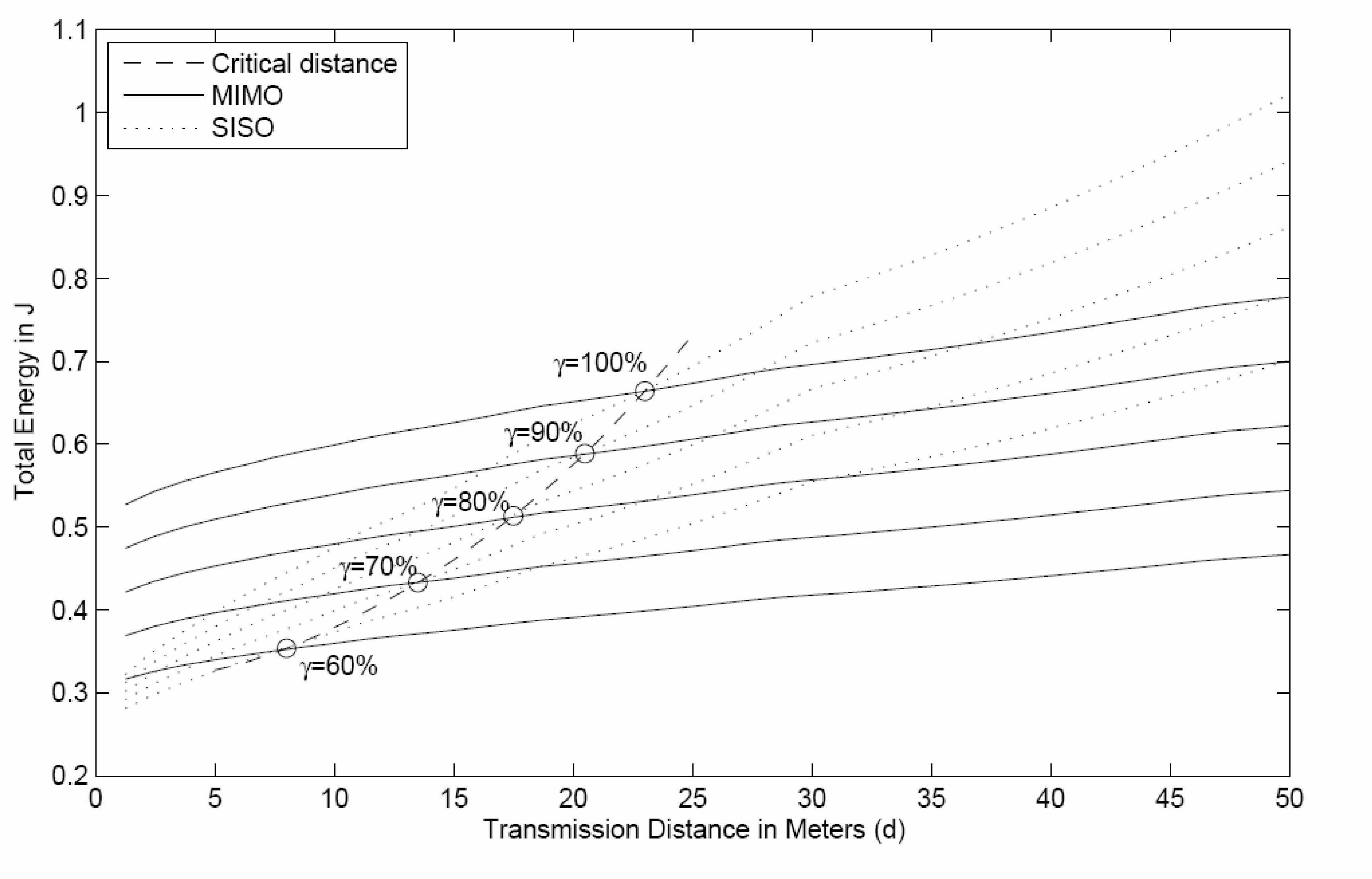


MIMO + Data Fusion A

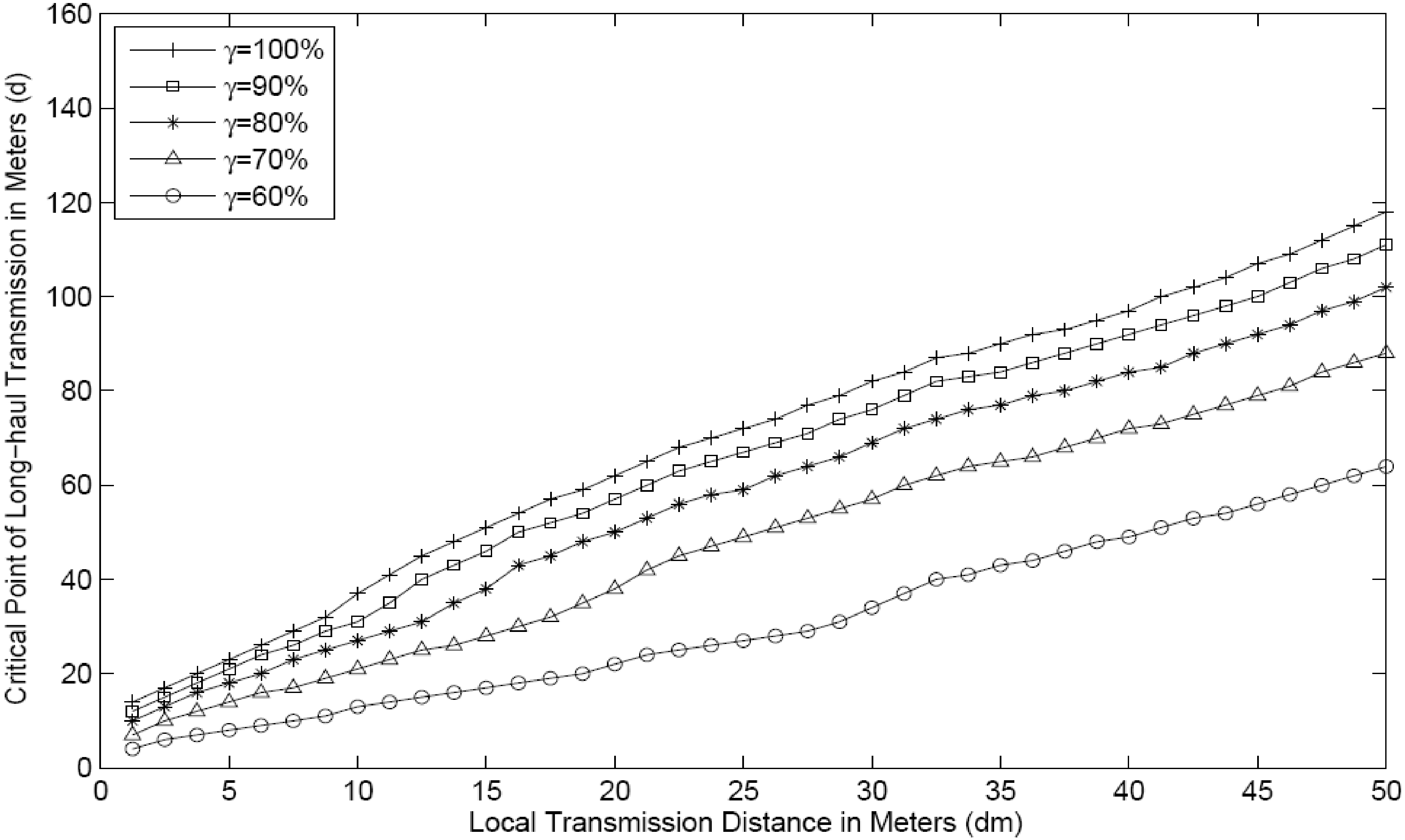


MIMO + Data Fusion B

Critical Point Shifts v.s. Data Redundancy

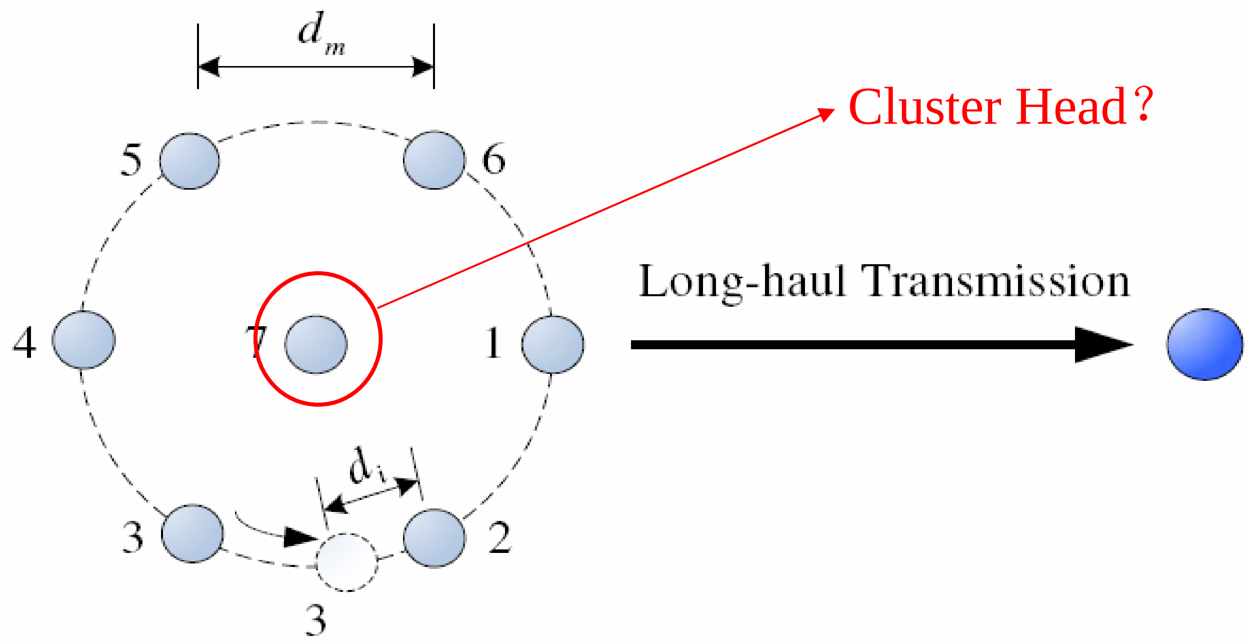


Critical Point Shifts v.s. Local Distance

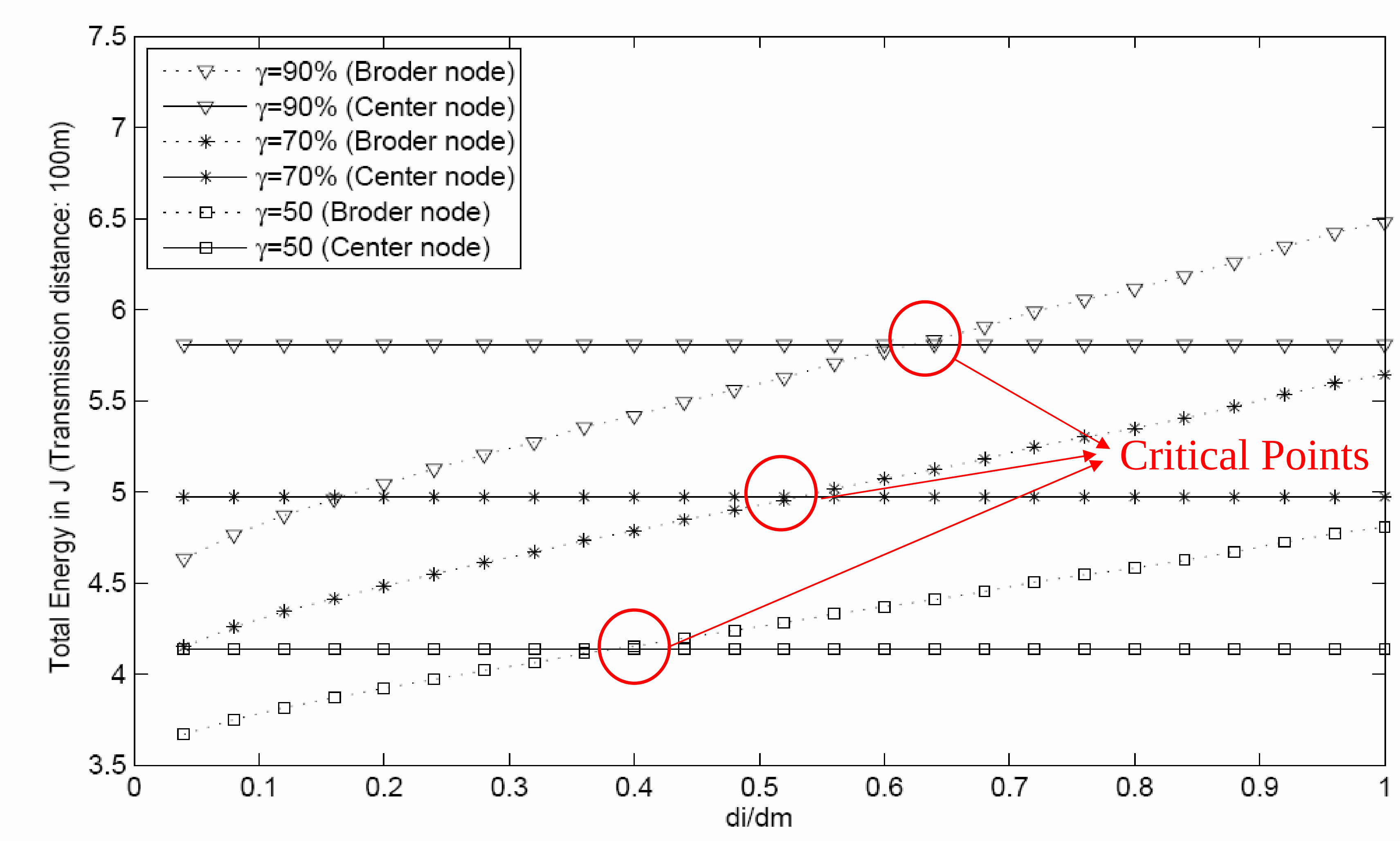


Someone Challenges Our Ideas

- Cluster-based Data Fusion is old
- C-MIMO is old
- It is trivial to combine this two ideas together



Header Selection and C-MIMO is coupled



Conclusion and Future Work

- C-MIMO outperforms SISO conditionally
- Data redundancy and local distance are two critical parameters
- Selection of fusion cluster-header and cooperative node are coupled questions.
- In the future, we will exploit an interesting problem:
  - Clustering C-MIMO Protocol for Wireless Sensor Networks supporting Content-rich Applications

Q&A

Thank You!