Energy Efficient Distributed JPEG2000 Image Compression in Multihop Wireless Networks

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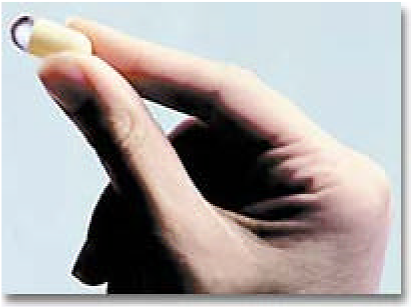
Outline

- Motivations
- Distributed Image Compression
- Energy Model
- Simulation
- Conclusion and Future Work

Motivations

- Recently, Visual Sensor Network is emerging for applications such as surveillance, environmental monitoring, security and interactive environments.
- It consists of tiny wireless-enabled battery-operated cameras.



Challenges and Objective

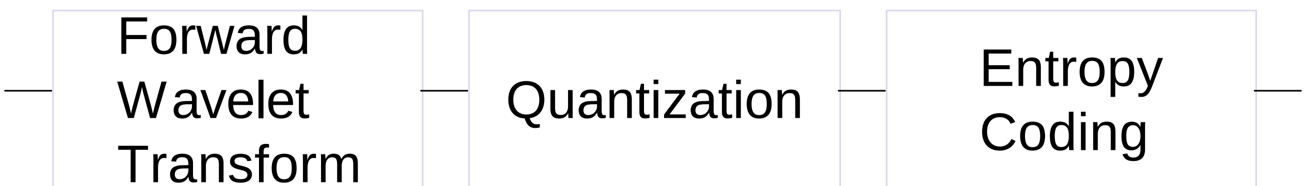
- Sensor networks will undergo a transition similar to the Internet transition from text-based to multimedia.
- Visual data incur high computation and communication energy →Sensors will remain relatively resource constrained
- “divide and conquer”
- Distributed image compression enables the sharing of computation load among sensors.

Assumptions

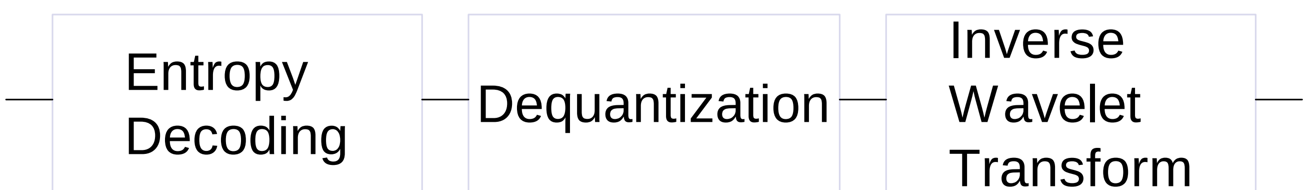
- Nodes, some of which are camera-equipped
- Cluster-based routing mechanism
- Contention-free and error-free
- Session: a source sending one image to a destination, in response to receiving a request from the destination
- In the request, Q (bit rate of compressed image) and L (wavelet decomposition level) are specified

Background on Image Compression

- Objective: Reduce Redundancy
- JPEG2000: wavelet-based, error resilience, progressive, multi-resolution
- Wavelet-based image coding:



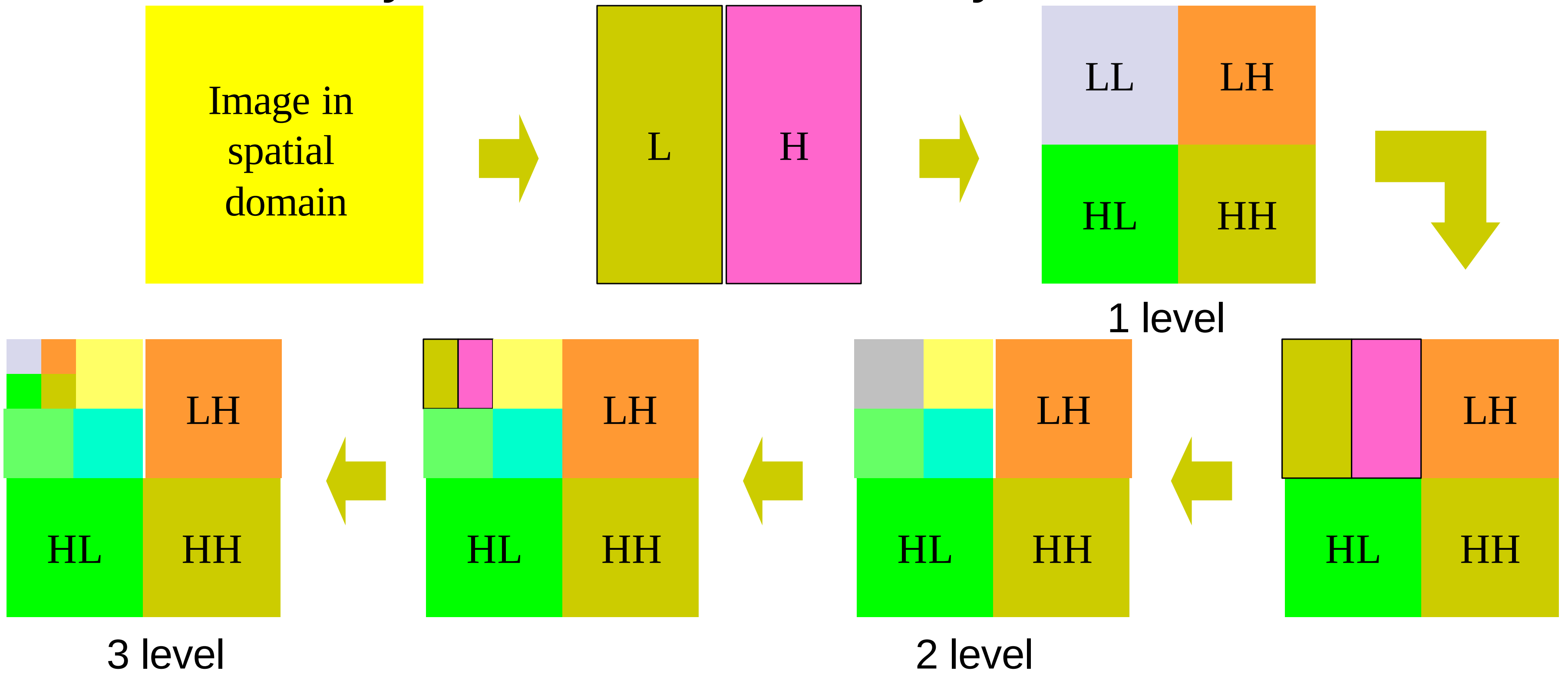
(a) Encoder



(b) Decoder

Wavelet Decomposition

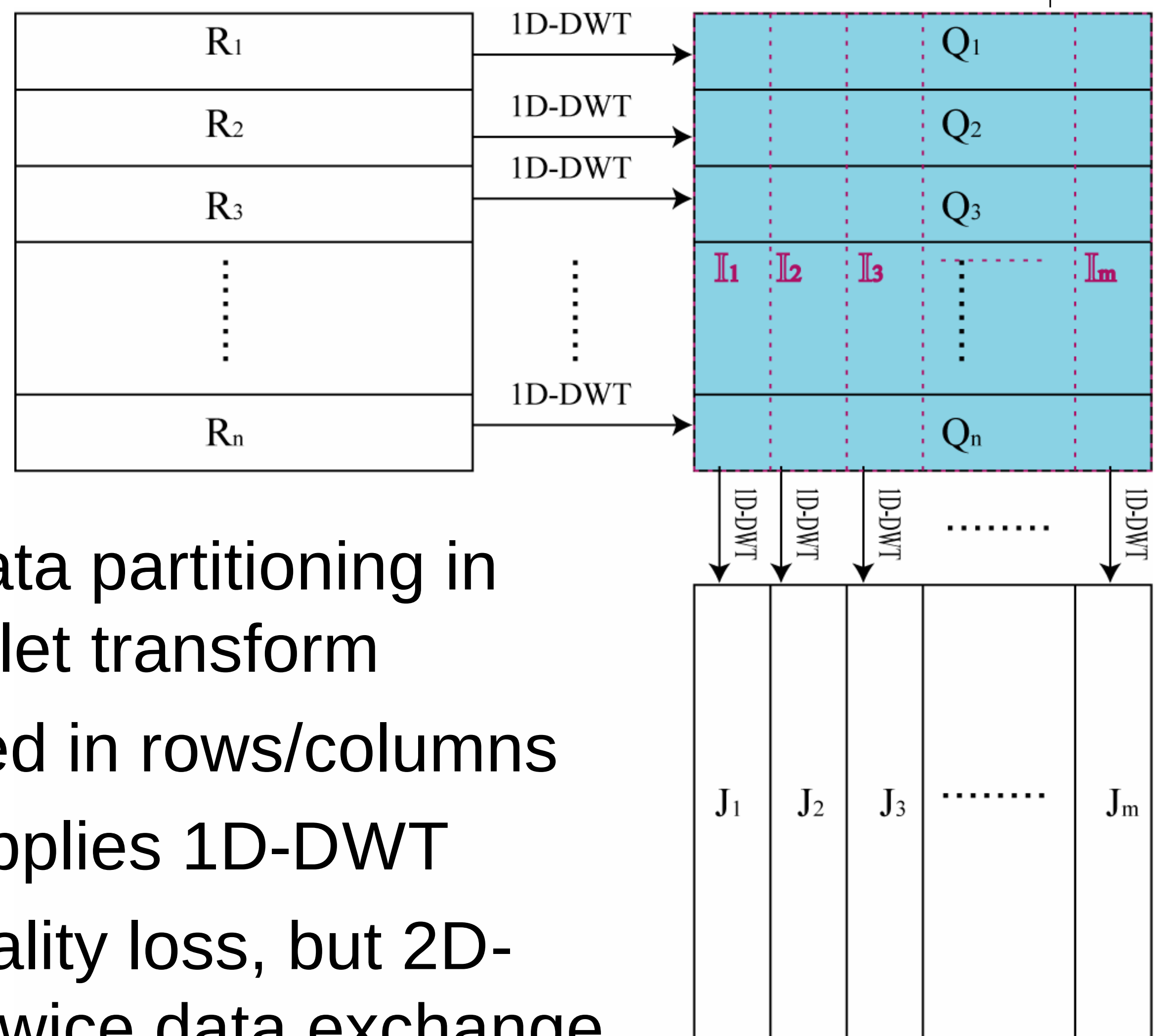
- Octave-band decomposition:
  - 1D-DWT applied to vertical and horizontal direction line by line: 2D-DWT.
  - The LL band is recursively decomposed, first vertically, and then horizontally.



Distributed Image Compression

- Wavelet transform consumes most energy in image compression.
- Basic idea: distributing the workload of wavelet transform to several groups of nodes along the path
- Data (raw image or intermediate results between decomposition levels) exchange is of key importance due the incurred wireless communication energy

Data Exchange Method 1



- Traditional data partitioning in parallel wavelet transform
- Data is divided in rows/columns
- Each node applies 1D-DWT
- No image quality loss, but 2D-DWT needs twice data exchange

Example of Method 1

Query and get node set info from cluster head

Source distributes compressed rows R_i to processing nodes

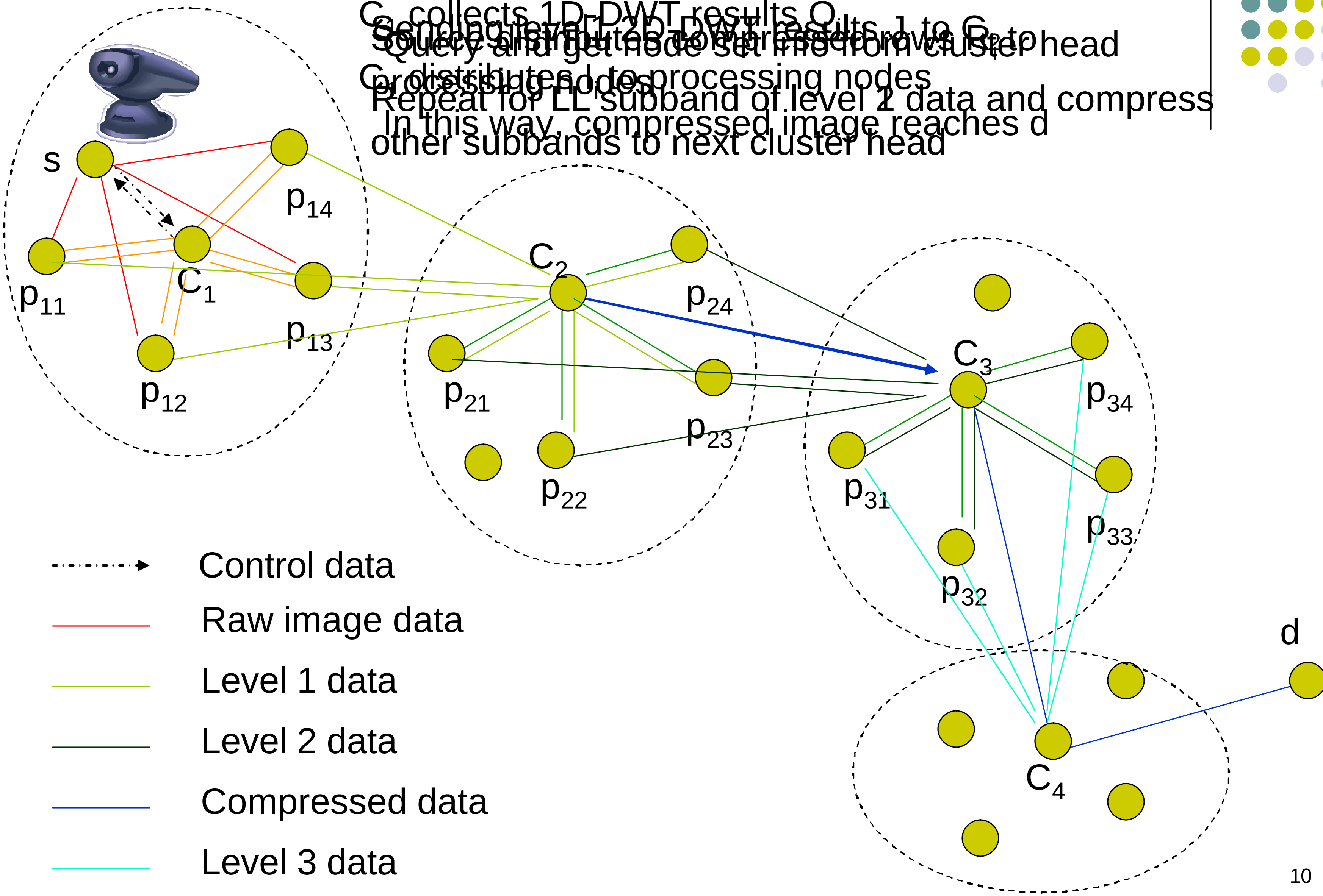
C_1 collects 1D-DWT results Q_i

C_1 distributes I_i to processing nodes

Sending level 1 2D-DWT results I_i to C_2

Repeat for LL subband of level 2 data and compress other subbands to next cluster head

In this way, compressed image reaches d



Data Exchange Method 2

- Tiling:

- Node does 2D DWT *independently*
- Rate-distortion loss and blocking artifacts increase with number of tiles

Example of Perceptual Image Quality with tiling

- Image quality loss and blocking artifacts are small if
  - Number of tiles is small or
  - Not very low bit rate
- Still applicable for distributed image compression

Top left: Without tiling.
0.1bpp,PSNR=29.30dB

Top right: Tile 64x64.
0.1bpp,PSNR=25.12dB

Btm. left: Tile 256x256.
0.1bpp,PSNR=29.12dB

Btm. right: Tile 64x64.
0.5bpp,PSNR =35.67dB

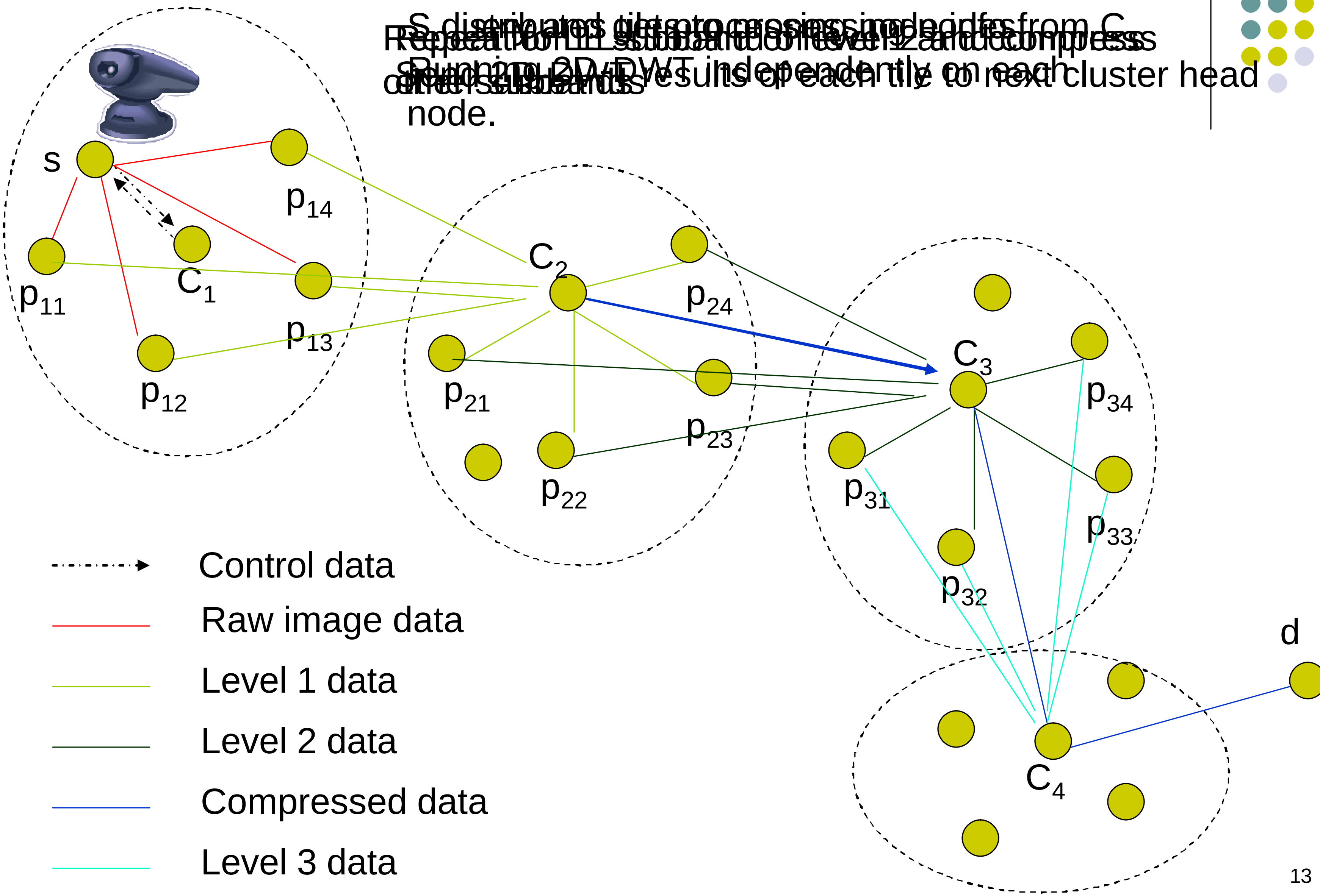
Example of Method 2

S distributes tiles to processing nodes from C

Running 2D-DWT independently on each node.

Repeat for LL subband of level 1 and compress other subbands

Send 2D-DWT results of each tile to next cluster head



Other Issues

- To save communication energy, entropy coding is applied before data exchange
- Randomly rotation of processing nodes in each cluster among sessions.

Energy Model

- Communication:
  - $E_{TX}=e_e+e_a d^a$ (Transmission) Joule per bit
  - $E_{RX}=e_e$ (Receiving)
  - e_e: startup energy parameter
  - e_a: amplifier energy parameter
  - a: path loss exponent
  - d: distance between transmitter and receiver
- Computation: (Estimated by JouleTrack on Jasper)
  - E_{DWT} = ? (1 level of 2D-DWT) Joule per raw image bit
  - E_{ENT} = d (Quantization and entropy coding)

JouleTrack: http://www-mtl.mit.edu/research/anantha/jouletrack/JouleTrack/index.html

JasPer: http://www.ece.uvic.ca/~mdadams/jasper/

Metrics

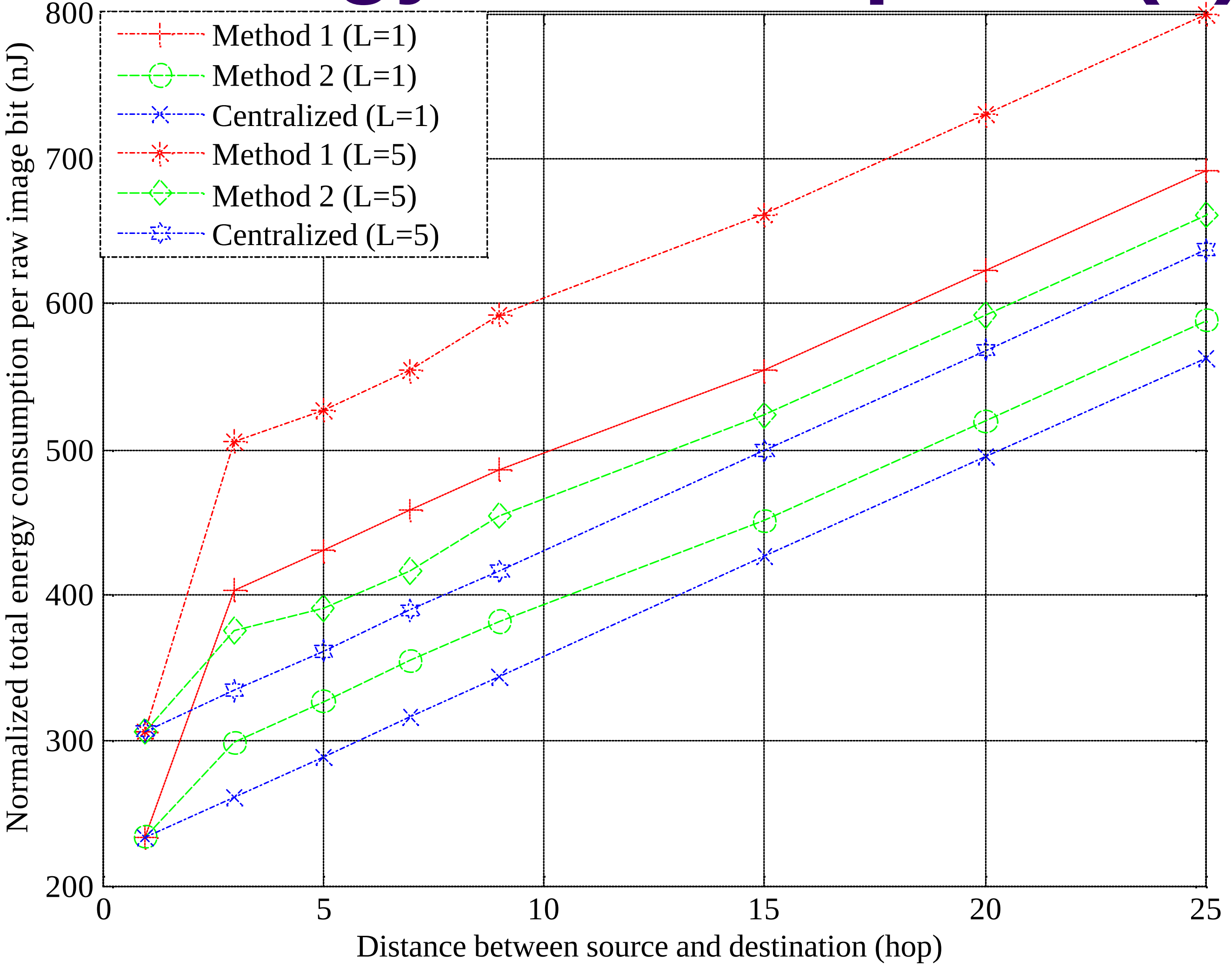
- Total energy: includes both computation and communication energy

- System lifetime: time when the first node in the network fails due to depleted energy.

Simulations

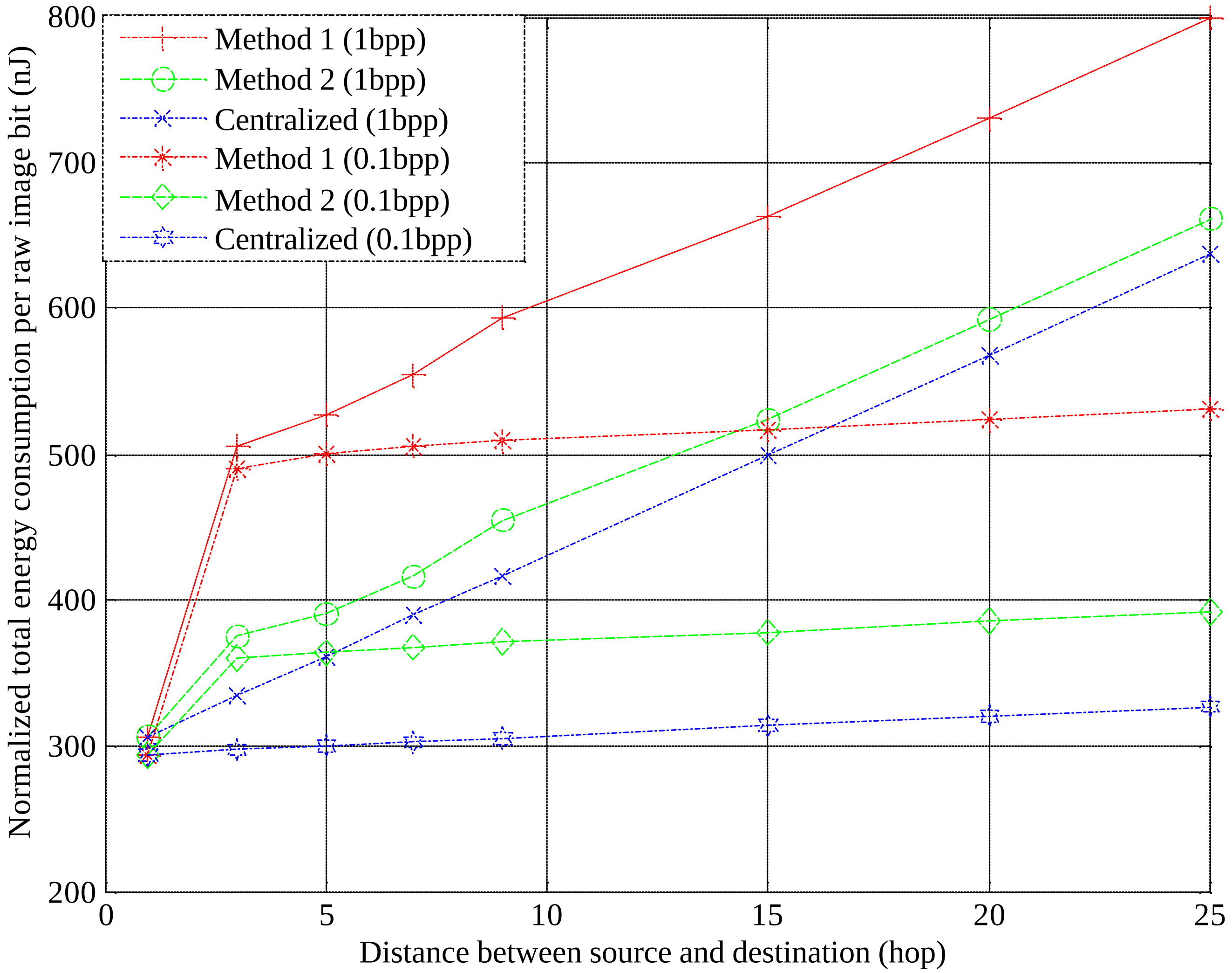
- 500 nodes
- Transmission radius=10m
- JPEG2000 code (in C) from Jasper

Total Energy Consumption (1)



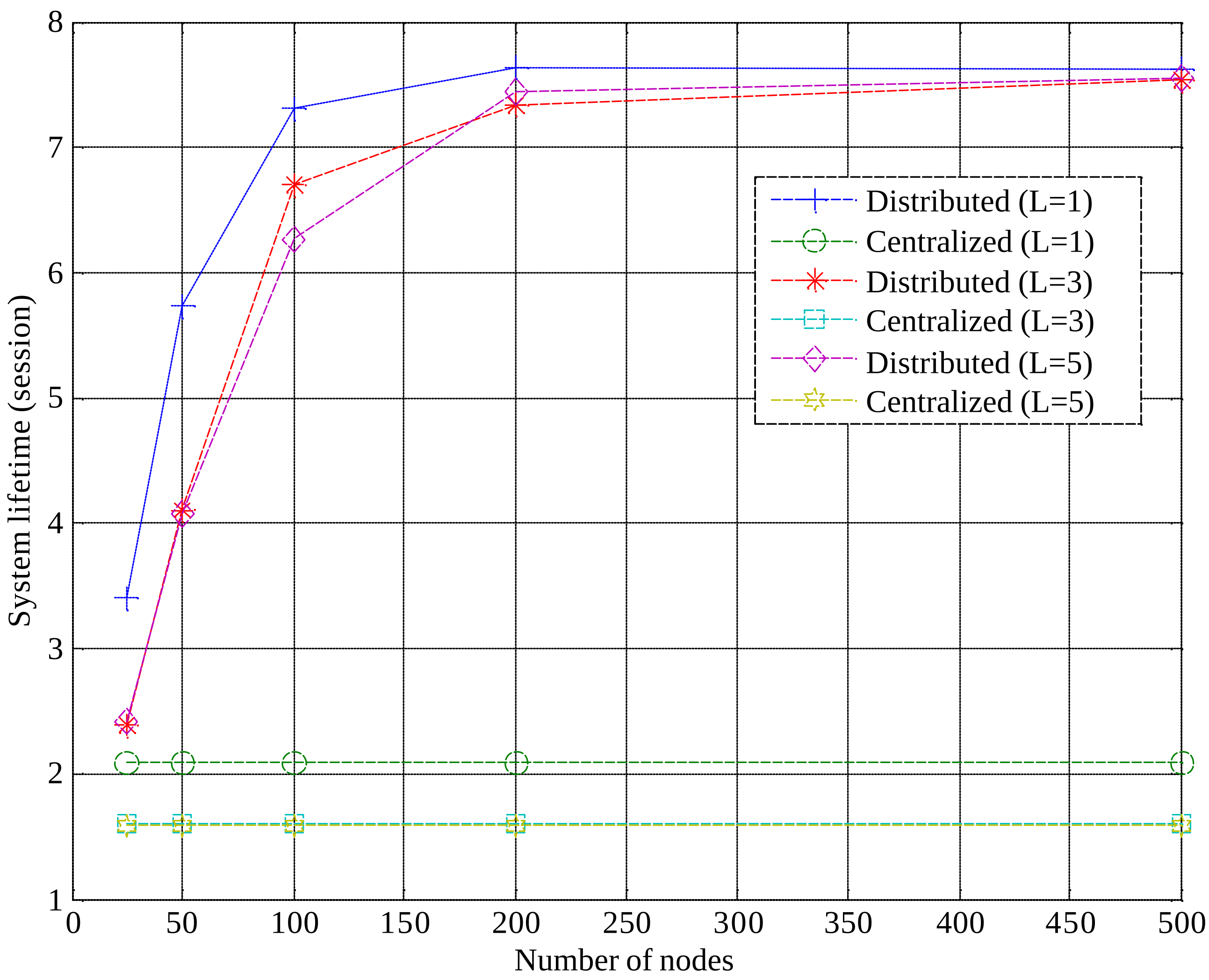
Total (comp.+comm) energy consumption per raw image bit versus distance between source and destination for different desired decomposition level L. Q=1bpp.

Total Energy Consumption (2)



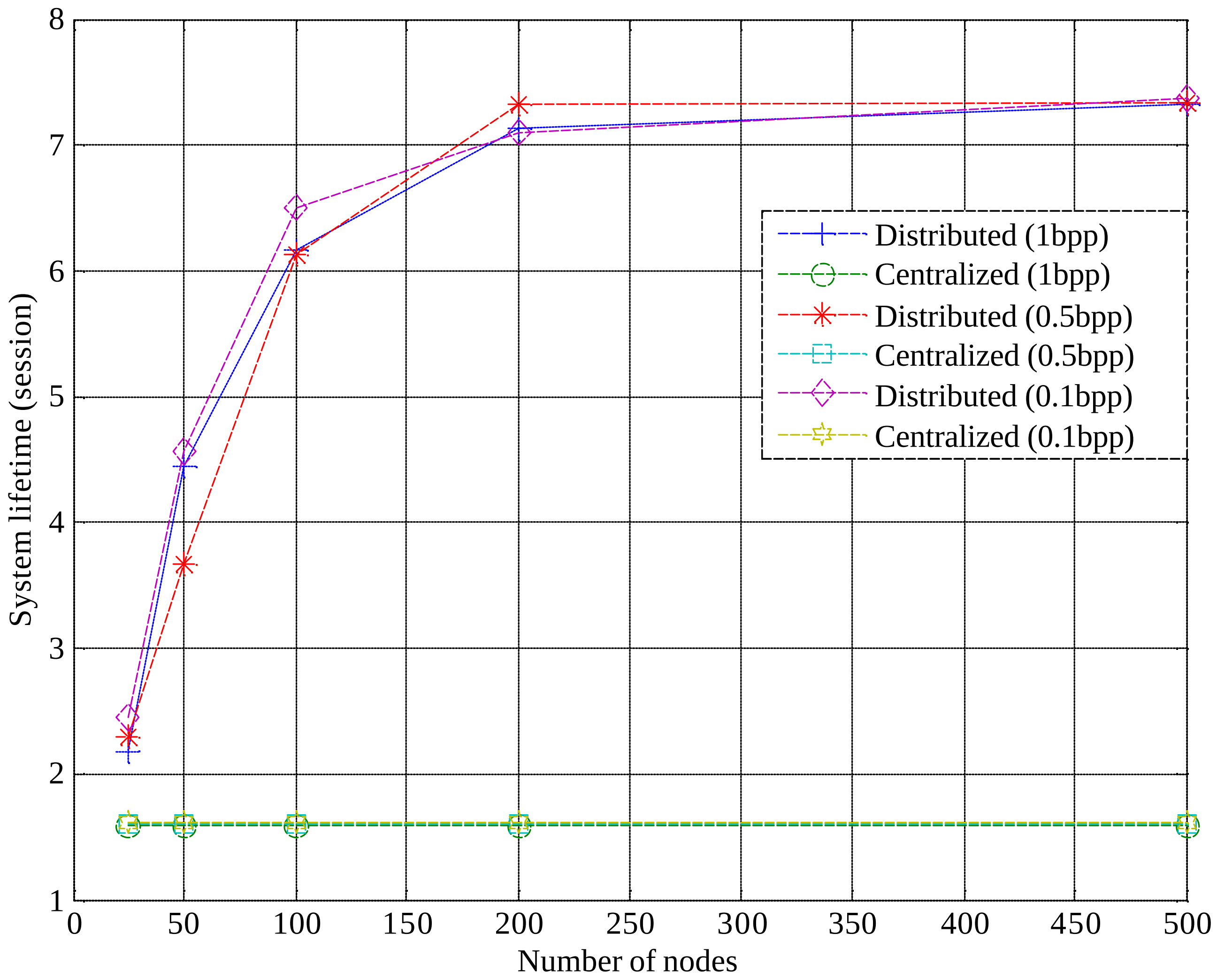
Normalized total energy dissipation per raw image bit versus distance between source and destination for different Q. L=5.

System Lifetime (1)



distributed (method2) versus centralized for different desired decomposition level L. Q=1bpp.

System Lifetime (2)



System lifetime comparison: distributed versus centralized for different Q. L=5.

Conclusion

- In terms of total energy consumption:
  - Method 1 is much higher than the other two (method 2 and centralized)
  - Method 2 is slightly higher than centralized image compression
- Method 2 extends the system lifetime by up to 4 times
- Simple and easy to implement

Future Work

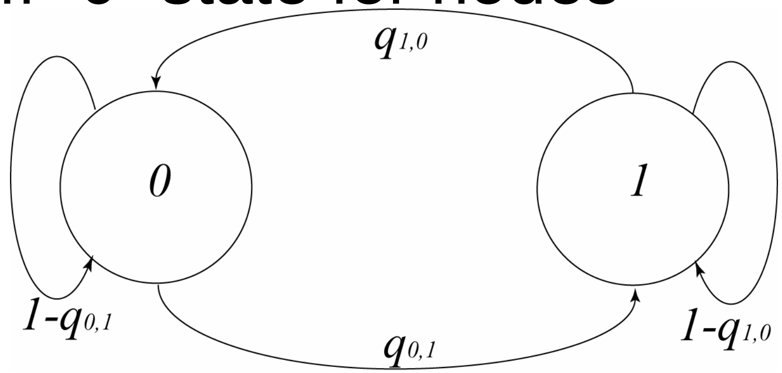
- Impact of wireless link errors
- Effect of node failure
- Dynamic number of processing nodes
- Multipath routing

Error Robust Distributed Image Transmission

- Sensor networks: error prone. Wireless link errors and node failures. -> Need mechanisms to provide reliability
- Distributed way is preferred for WSN
- Add spatial redundancy (e.g. FEC, multipath) not temporal redundancy (e.g. ARQ) to image/video surveillance: real time applications.

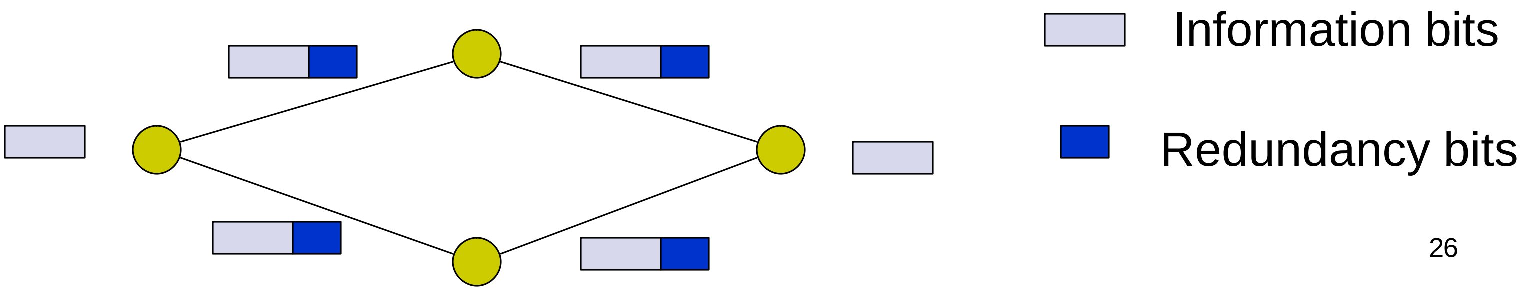
Network Assumptions

- Average wireless channel error probability: P_e
- Sensor node failure probability: P(off)
- No failure detection service to predict node failure
- Both can be modeled by a Markov chain:
  - Good “1” or bad “0” state for wireless channels
  - On “1” or off “0” state for nodes

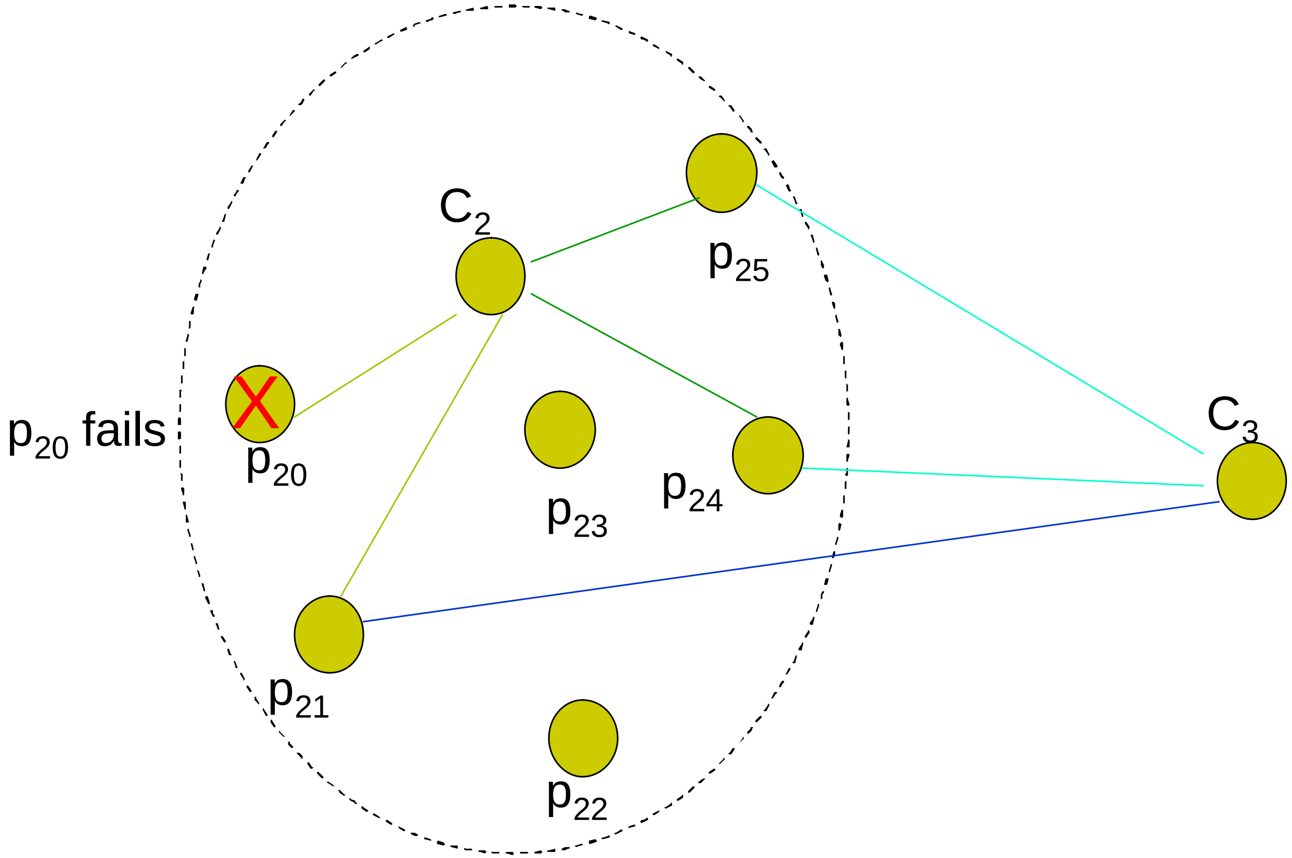


Error Robust Distributed Image Transmission

- 2 components: FEC-based unequal error protection and path diversity
- Choose Reed-Solomon (RS) code. UEP by selecting different k for RS(n,k) code
- Randomly choose multiple forwarding nodes in a cluster
- Combining multiple copies of coefficients from different nodes



Example



Cluster head C_2 sends 2 copies of level 1 data of tile 0 to p_{20} and p_{21}

Cluster head C_2 sends 2 copies of level 1 data of tile 1 to p_{24} and p_{25}

Cluster head C_3 gets level 2 data of tile 0 from p_{21}

Cluster head C_3 combines level 2 data of tile 1 from p_{24} and p_{25}

Simulations

- Image quality: PSNR
- Overhead: energy consumption per node
- 4 schemes:
  - (A) no error protection
  - (B) only FEC code
  - (C) only path diversity
  - (D) our proposed scheme (FEC+multiple nodes)

Relative energy consumption

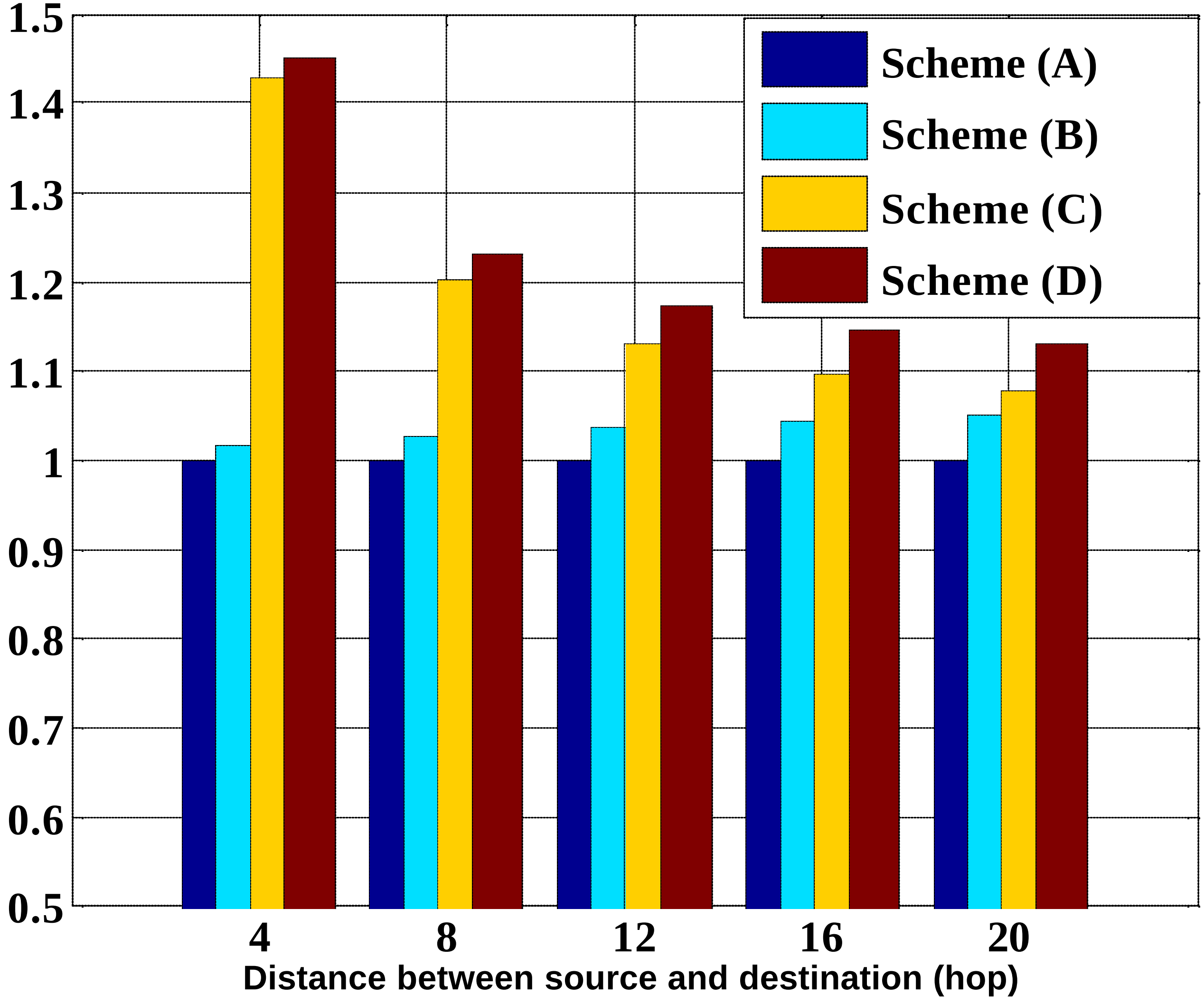


Image quality vs. distance between source and destination

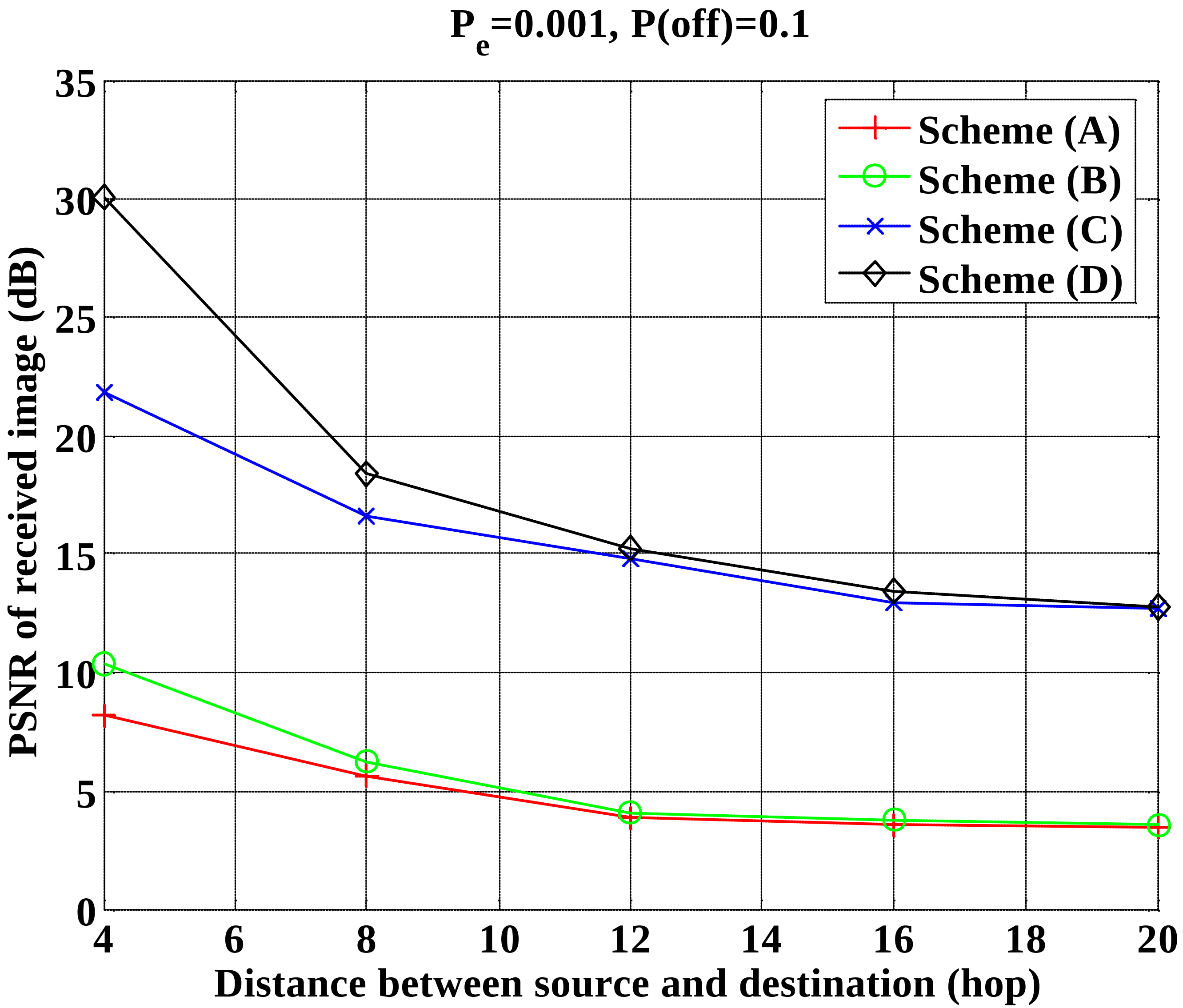


Image quality vs. P_e

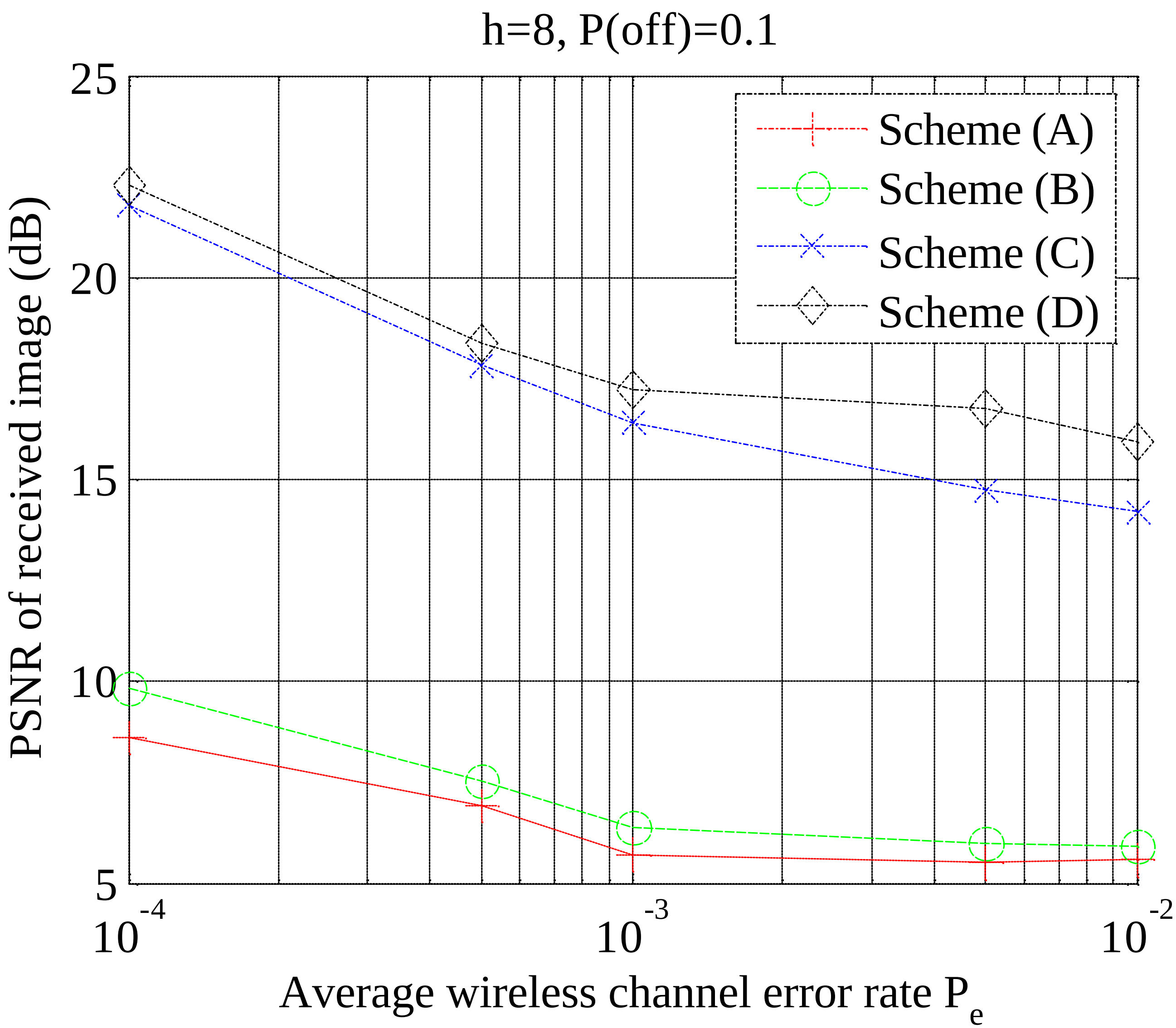
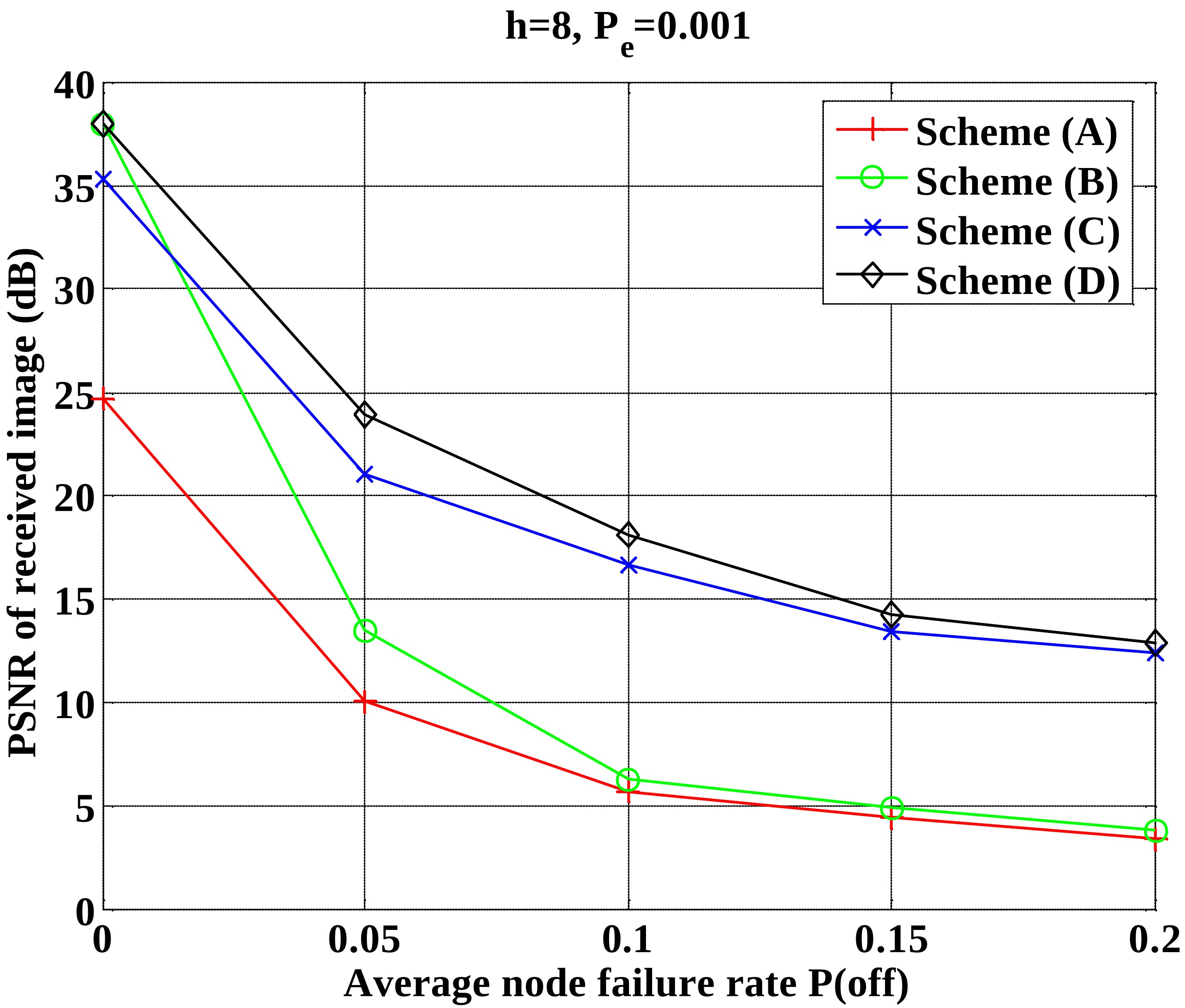


Image quality vs. P(off)



Comparison of perceptual image quality

Scheme (A), Scheme (B)
Scheme (C), Scheme (D)

P_e=5 x10^{-3},P(off)=0.02, h=4.

Results

- The difference between scheme (A) and (B) is very small. As well as the difference between scheme (C) and (D). -> Impact of RS coding on energy consumption is small.
- The normalized total energy consumption decreases with the increase of h and almost becomes flat for large h. The energy consumed in image compression is distributed into more nodes for large h.
- Low energy overhead: about 20% more than scheme (A)
- Image quality improvement: up to 10 dB and better perceptual image quality

Thank You!