Energy Consumption Analysis of a Simple Image Transmission Protocol in Wireless Sensor Networks

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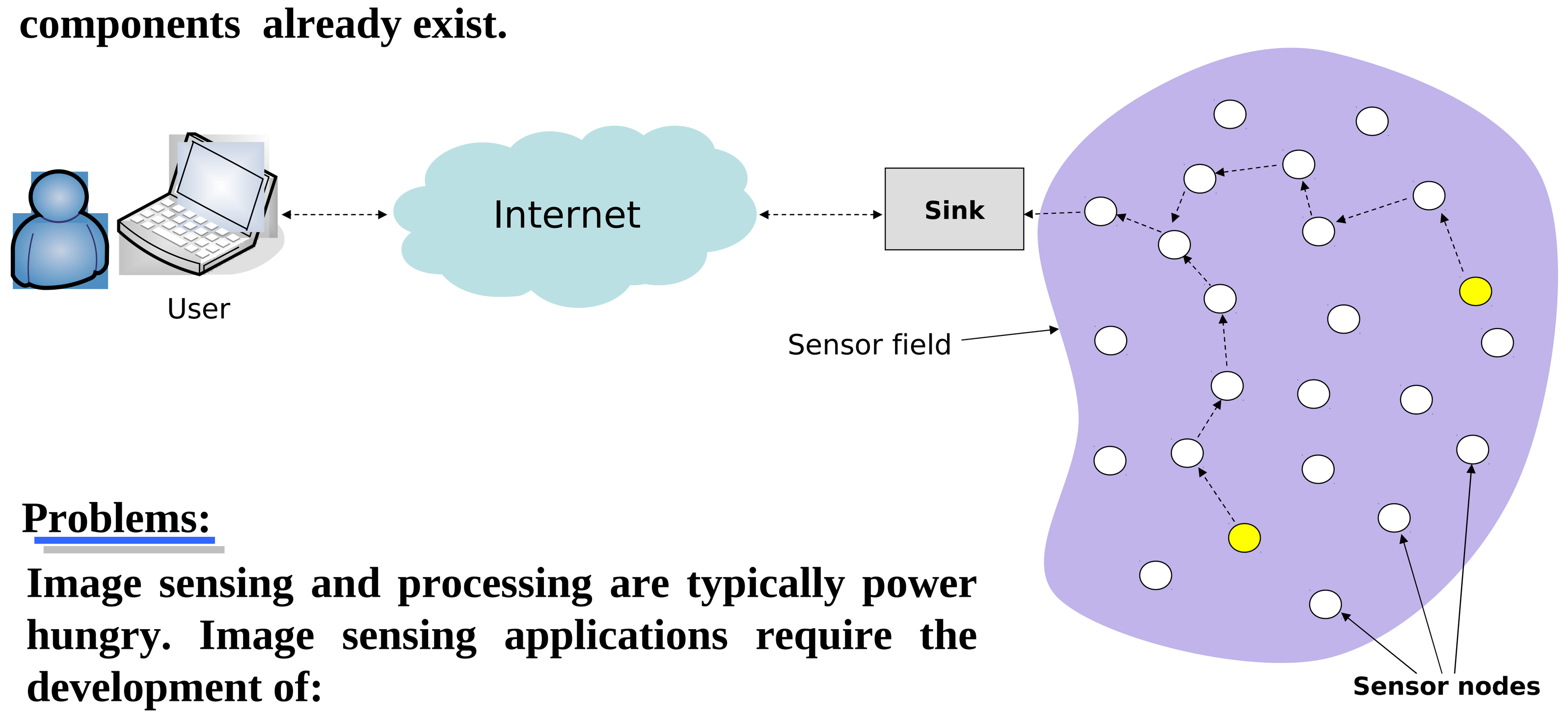
Image Transmission in WSN

Many potential applications of Wireless Sensor Networks (WSN), like object detection, recognition, localization, and tracking, require vision capabilities. Nowadays, such applications are possible since sensors equipped with visioning components already exist.



Problems:

Image sensing and processing are typically power hungry. Image sensing applications require the development of:

- small, low-power and low-cost image sensors
- energy-efficient algorithms for image compression
- energy-efficient protocols for image communication

Proposal

Considering that most of the WSN node's energy is spent in radio transmission (in comparison with the rest of the components), we propose a self-adaptive image transmission protocol driven by energy efficiency considerations. This one is based on wavelet image transform and semi-reliable transmission to achieve energy conservation.

At the source node:

Wavelet image transform provides data decomposition in multiple levels of resolution. As a result, image data can be divided into p priority levels that correspond to the resolution ones.

At intermediate nodes:

In the hop-by-hop perspective, all data packets are reliably transmitted, *i.e.*, packets are acknowledged and retransmitted if lost.

Semi-reliable transmission is considered from the end-to-end perspective, *i.e.*, some data packets can be discarded by a node with respect to its battery state-of-charge and the packets priority.

Data packet format:

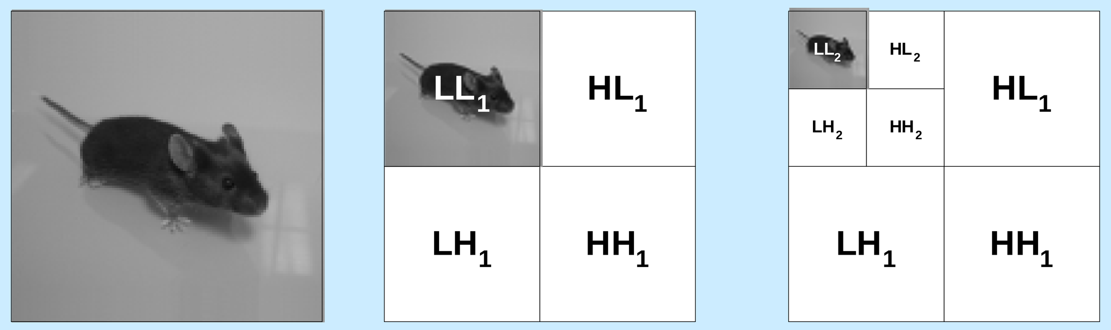
Header of 4-byte long

Image ID	Data offset	p	ℓ	Payload

Technical Principles

2D Discret Wavelet Transform

2D Discret Wavelet Transform (DWT) divides an image in 4 subbands by applying a low-pass L and a high-pass H filters on the lines of the sample and, afterwards, of the output columns.



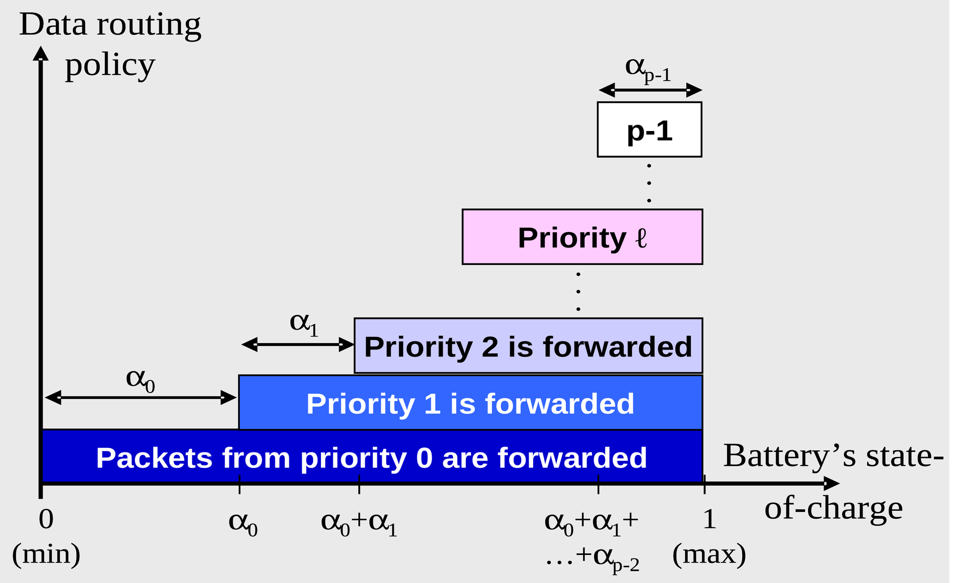
(a) Original Image (b) One 2D DWT applied (c) Two 2D DWT applied

- The LL subband represents a down-sampled low-resolution version of the input image.
- The others subbands contain the detail informations, needed for the perfect reconstruction of the input image from the low-resolution version.

Priority-Based Scheme

Packets from a given priority level are forwarded by an intermediate node only if its battery state-of-charge is greater than a given threshold.

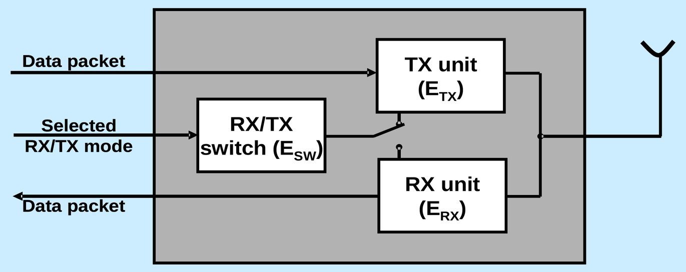
The priority-based drop scheme is defined by $\{\alpha_0, \alpha_1, \ldots, \alpha_{p-1}\}$, the set that determines the minimum energy level for each priority level.



Nodes Power Consumption

Energy consumed to transmit a *k-byte* message between neighbor nodes:

$$E(k) = 2.E_{SW} + E_{TX}(k,P_{out}) + E_{RX}(k)$$



Energy consumed to apply the 2D-DWT, p times in a MxN image:

$$E_{DWT}(M,N,p) = (10\varepsilon_{shift} + 12\varepsilon_{add} + 2\varepsilon_{rmem} + 2\varepsilon_{wmem}).MN.\sum_{i=1}^{p}\frac{1}{4^{i-1}}$$

Image Transmission Energy Model

Let $R(\ell, n)$ be the probability that packets with priority ℓ are transmitted until the sink through n intermediate nodes:

$$R(\ell,n) = (\alpha_\ell + \alpha_{\ell+1} + \ldots + \alpha_{p-1})^n$$

Let $B(\ell, i)$ be the probability that packets with priority ℓ are only transmitted until the i^{th} node:

$$B(\ell,i) = (\alpha_0 + \alpha_1 + \ldots + \alpha_{\ell-1}).(\alpha_\ell + \alpha_{\ell+1} + \ldots + \alpha_{p-1})^{i-1}$$

Average amount of energy spent to transmit an image

$$E_T = \underbrace{(n+1).m_0.E(t_0)}_{\text{Energy spent to send data from the resolution 0}} + \sum_{\ell=1}^{p-1}\underbrace{\left[R(\ell,n).(n+1).m_\ell.E(t_\ell) + \sum_{i=1}^{n} B(\ell,i).i.m_\ell.E(t_\ell)\right]}_{\text{Energy spent to send data from the resolution } \ell}$$

- n : Number of intermediate nodes between the image source and the sink.
- m_ℓ : Number of packets required to transmit image data from the resolution level ℓ (the average size being t_ℓ bytes).
- p : Number of image resolutions, enabled by using DWT.

Results

Numerical results show the energy saving in semi-reliable image transmission scheme compared to a full-reliable one:

- The amount of energy spent by hop is constant when a full-reliable protocol is considered for image transmission.
- Results show up to 72% energy saving with semi-reliable protocol, considering image decomposed into two resolution levels.
- Results show up to 90% energy saving with semi-reliable protocol, considering image decomposed into three resolution levels.

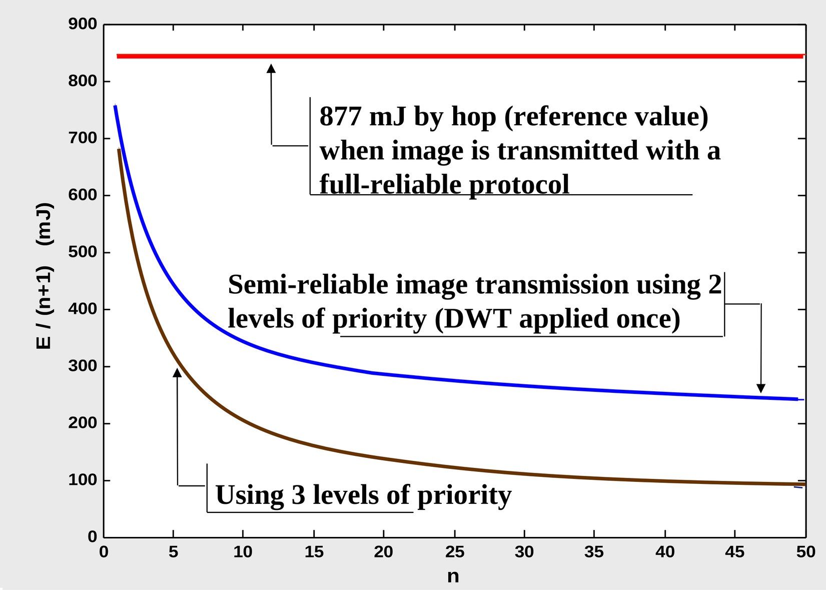
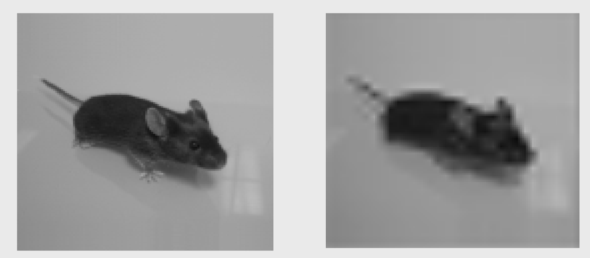


Image quality *vs.* energy saving :



Loss-free image PSNR=50.97 dB

Image played out in the worst case PSNR=32.25 dB

Conclusion

The preliminary results obtained from the energy consumption analysis are promising. Our image transmission protocol provides a graceful trade-off between the image quality played out and the sensor nodes lifetime. This protocol is very simple to implement on sensor nodes. Currently, we investigate the impact of compression algorithms and non-uniform distributions on the energy saving.