Performance Evaluation of IEEE 802.15.4 and 802.11 Protocols for Image Transmission in WSNs

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Outline

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- Motivation and contributions
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- Experimental setup
  - Simulation scenarios
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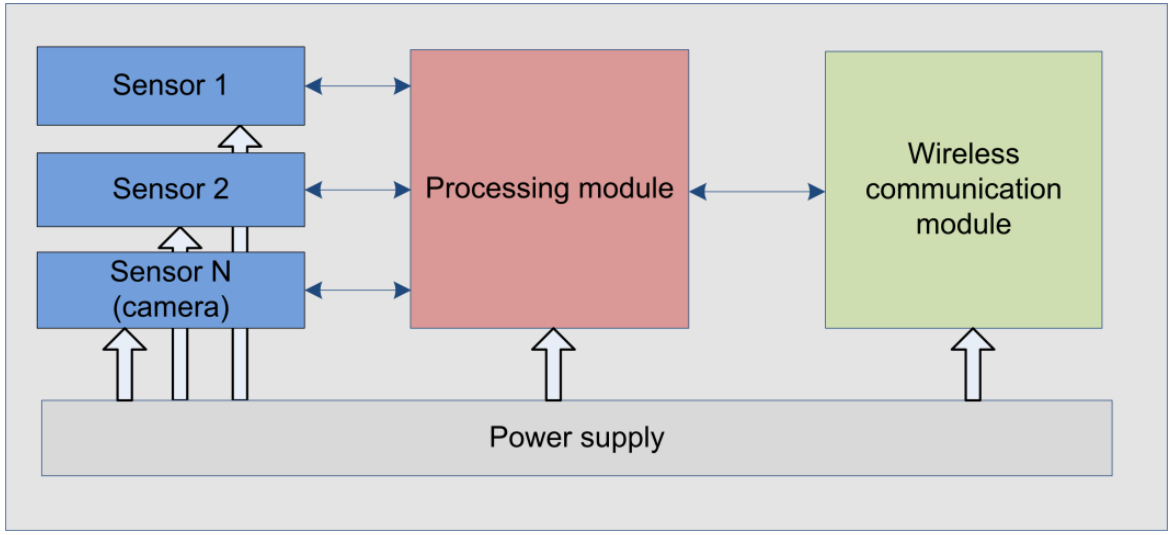
Introduction

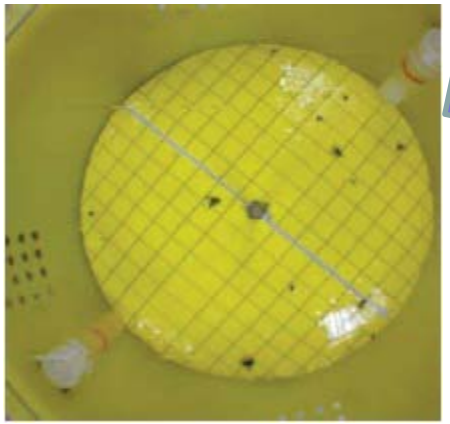
- Wireless sensor nodes → limited energy budget
- Energy constraints
  - Data acquisition, data processing and data transmission
- High-resolution cameras in WSNs
  - High consuming data acquisition
  - Large amount of data
- Processing vs. communication trade-off[1]



1) Ferrigno *et al.*: "Balancing computational and transmission power consumption in wireless image sensor networks", VECIMS, 2005 .

Application requirements

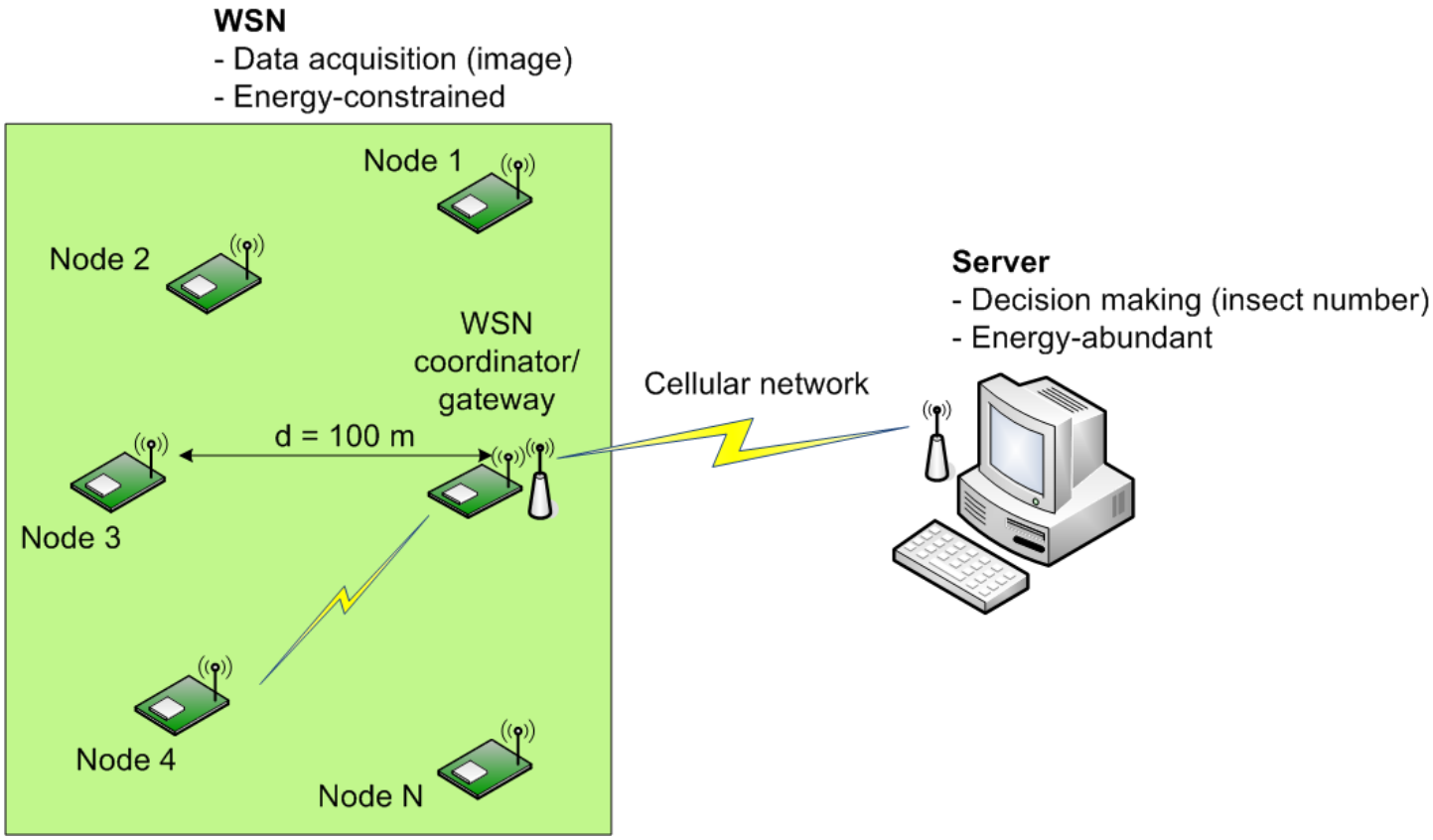
- Our interest: pest monitoring[2,3]
- Image resolution
  - 8 MPix → 24 MB raw image



2) Jelicic *et al.*: “MasliNET: A wireless sensor network based environmental monitoring system”, *34th Int’l Convention MIPRO*, 2011.
3) Lopez *et al.*: “Monitoring pest insect traps by means of low-power image sensor technologies”, *Sensors,* vol. 12, 2012.

Application scenario

- Image acquisition – rarely (once a day)
- Raw image transmission
- Challenge: Which communication protocol to choose?



Motivation & Contributions

MOTIVATION:

- Choose a wireless communication protocol that minimizes node's energy consumption while transmitting a high-resolution image.

CONTRIBUTIONS:

- A systematic elaboration of requirements and constraints for image transmission in a WSN-based pest monitoring system;
- Simulation experiments and comparisons of IEEE 802.15.4 and IEEE 802.11 protocols in terms of energy-efficiency and performance.

IEEE 802.15.4 vs. 802.11

- Requirements:
  - Range (100 m)
  - Low energy consumption

- IEEE 802.15.4/ZigBee
  - WSN standard(s)
  - Low energy consumption
  - 250 kbps
  - 127 B max packet size
  - Modification for image transmission[4]

- IEEE 802.11
  - Communication between computers
  - High energy consumption
  - High bit rates
    - b: 1-11 Mbps
    - g: 6-54 Mbps
  - Bigger packet size
  - Data transfer rate limitation (Wi-Fi module → sensor node) - UART, SPI
  - ah[5] - still not extensively tested

4) Jelicic *et al.*: "Reducing power consumption of image transmission over IEEE 802.15.4/ZigBee sensor network", *IEEE Instrum. and Meas. Technology Conf.* (I2MTC), 2010.
5) Olyaei *et al.*: "Performance comparison between slotted IEEE 802.15.4 and IEEE 802.11ah in IoT based applications", *IEEE WiMob*, 2013.

Experimental setup

- Simulations in OMNeT++
  - Models from INET-MANET framework
- Image transfer (24 MB data block) between two nodes
  - Monitor energy consumption of the sending node
  - Acknowledgments (retransmissions)
- Communication channel – free space radio propagation model:

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^\alpha L}$$

$$SNR = \frac{P_r}{P_N}$$

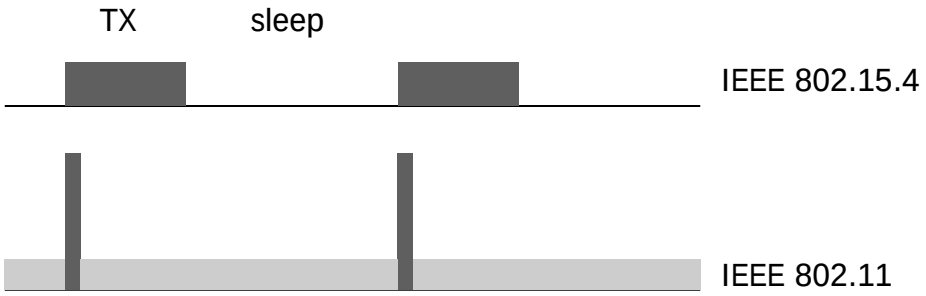
- Simulation parameter
  - Thermal noise P_N varied from -100 dB to -84 dB
- PHY, MAC layers simulated only!

Experimental setup

- IEEE 802.15.4
  - Sender RFD, receiver FFD
  - Non-beacon mode
  - Full packets (118 B payload)
- IEEE 802.11b/g
  - Receiver access point
  - 100 ms beacon interval
  - 1024 B payload

Current consumption per radio state

Radio state	Current consumption [mA]	
	IEEE 802.15.4	IEEE 802.11
Sleep	0.06	0.1
Idle	1.38	50
Rx	9.6	130
Tx	16.24	200



Overall energy consumption:

a) Radio energy consumption for image transmission
b) Radio energy consumption in sleep state

Explore

- Duty cycle (time and energy consumption when transmitting and sleeping)
- Influence of collisions, signal-to-noise ratio (SNR) and data transfer rate limitation on energy consumption of the sending node.

Simulation scenarios

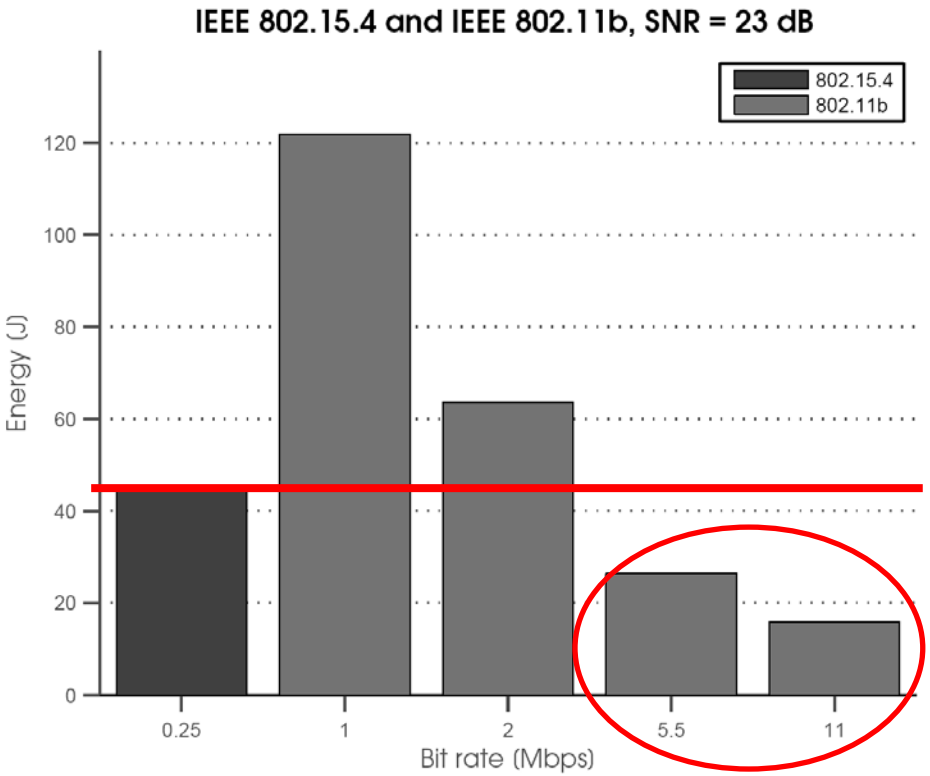
a) Collisions
- Clear channel
- Busy channel – two nodes transmitting contemporaneously
- Without bit errors (P_N = 100 dB, SNR = 23 dB)

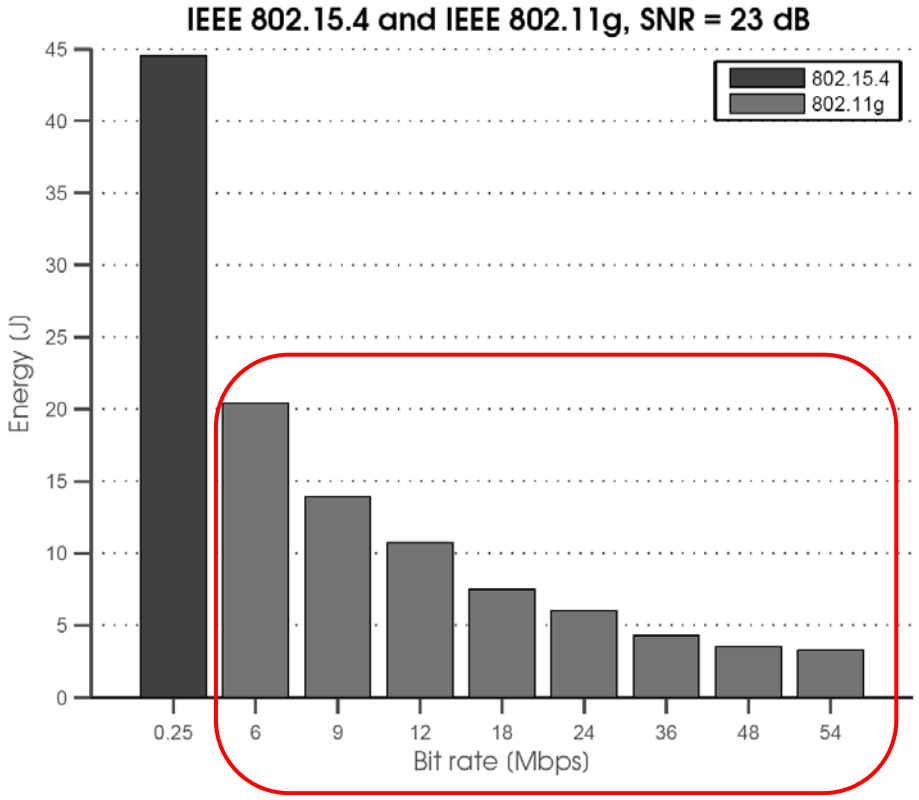
b) SNR
- SNR = 23 dB ... 7 dB
- Lower SNR → higher bit error rate

c) Data transfer rate limitation
- unilimited data transfer rate
- 3 Mbps limitation
- 5 Mbps limitation

Results: Ideal conditions

- Without collisions
- Without data transfer rate limitation
- Without bit errors
- Higher bit rates → lower energy consumption

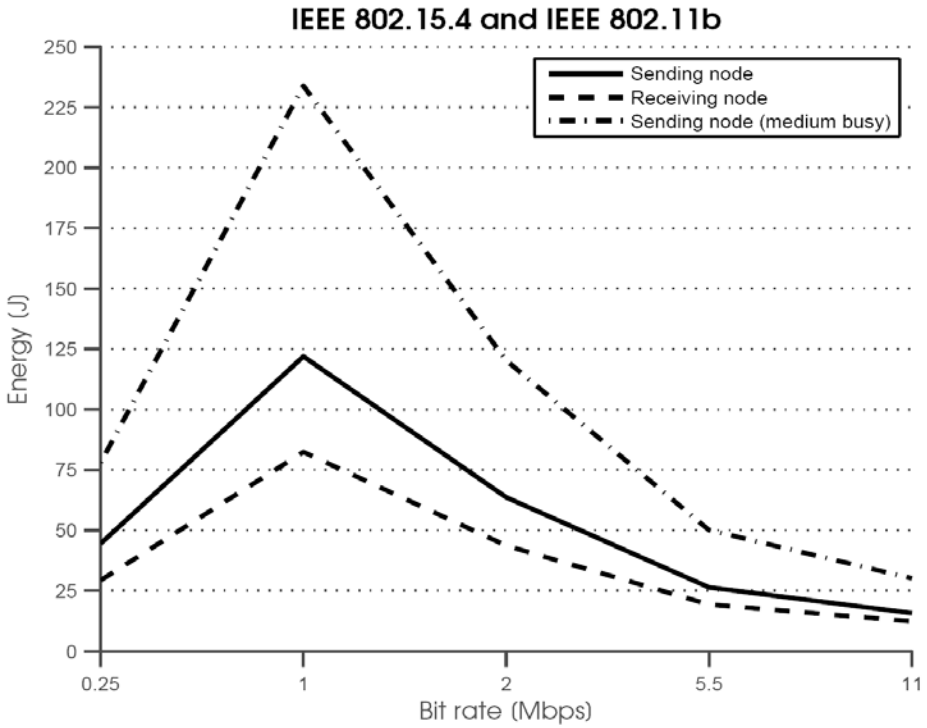


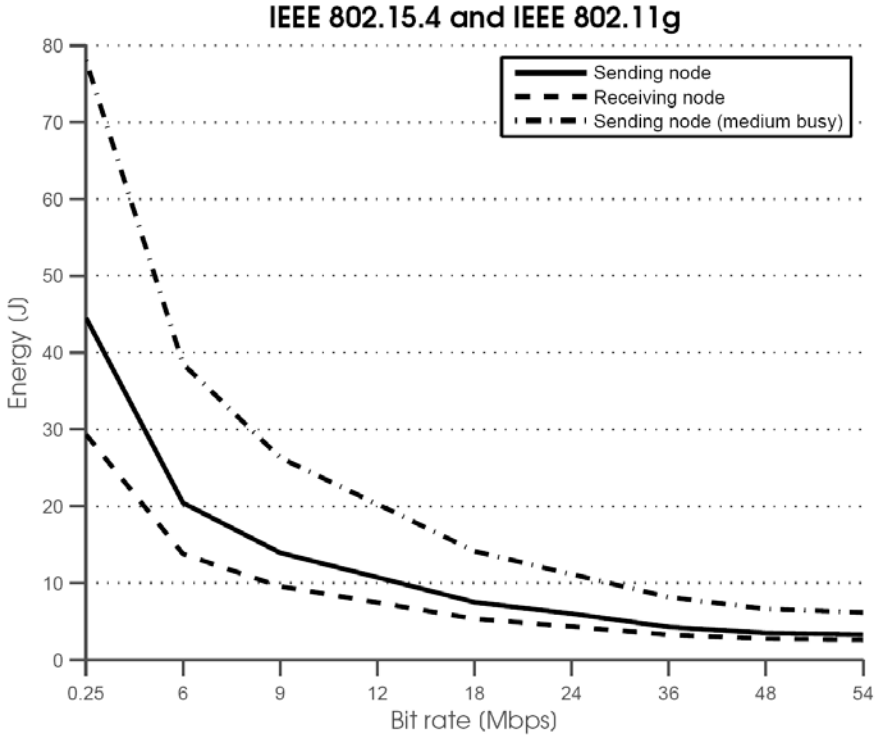


Results: Influence of collisions

- 2 nodes transmitting at the same time

- Lower effective bit rate
- Almost double energy consumption

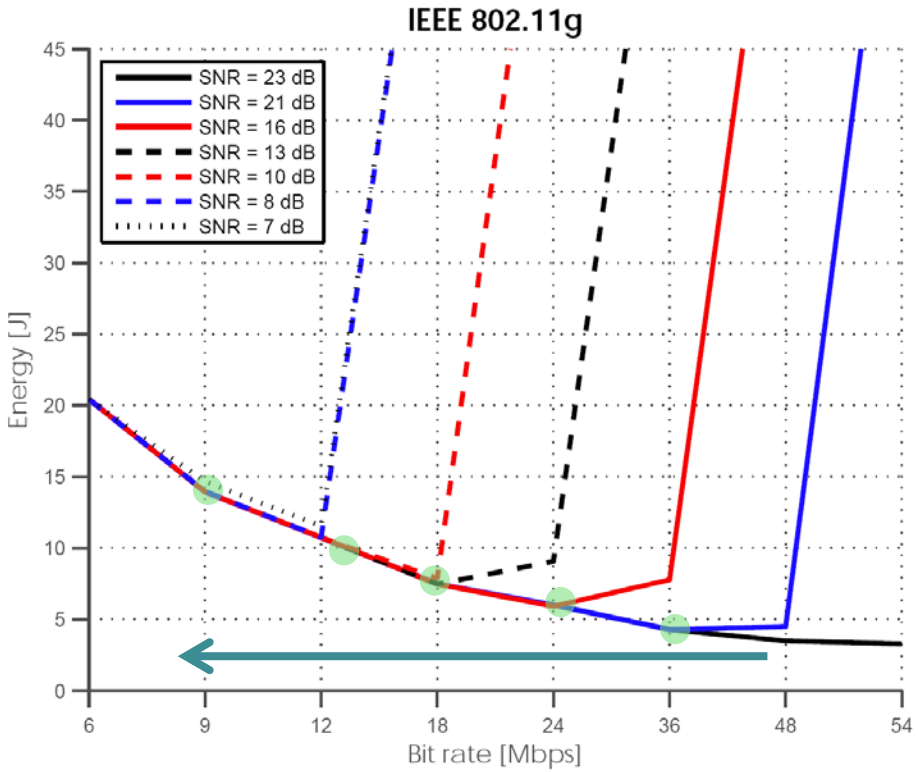




Results: Influence of SNR

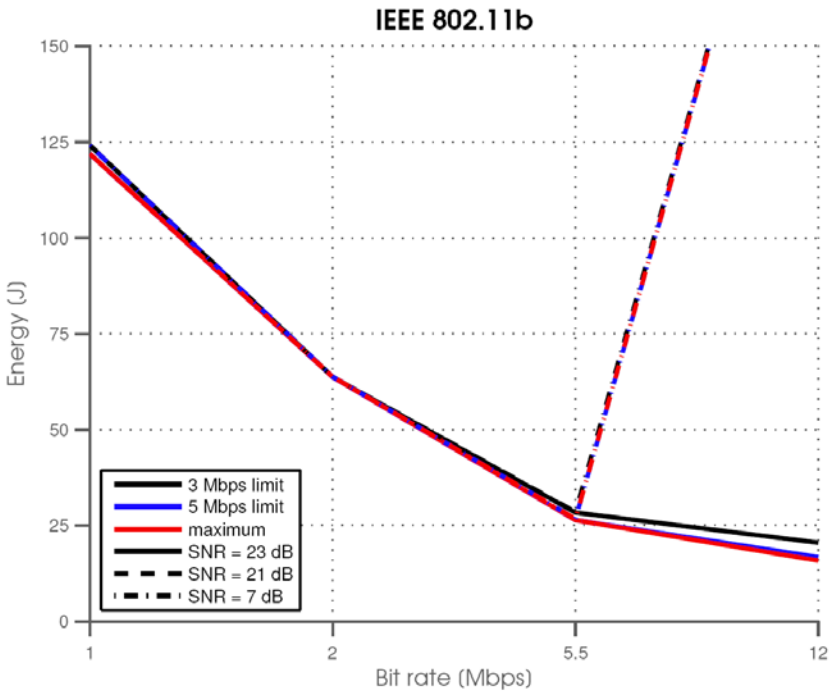
- IEEE 802.11g → best energy-efficiency
  - But more susceptible to bit errors!

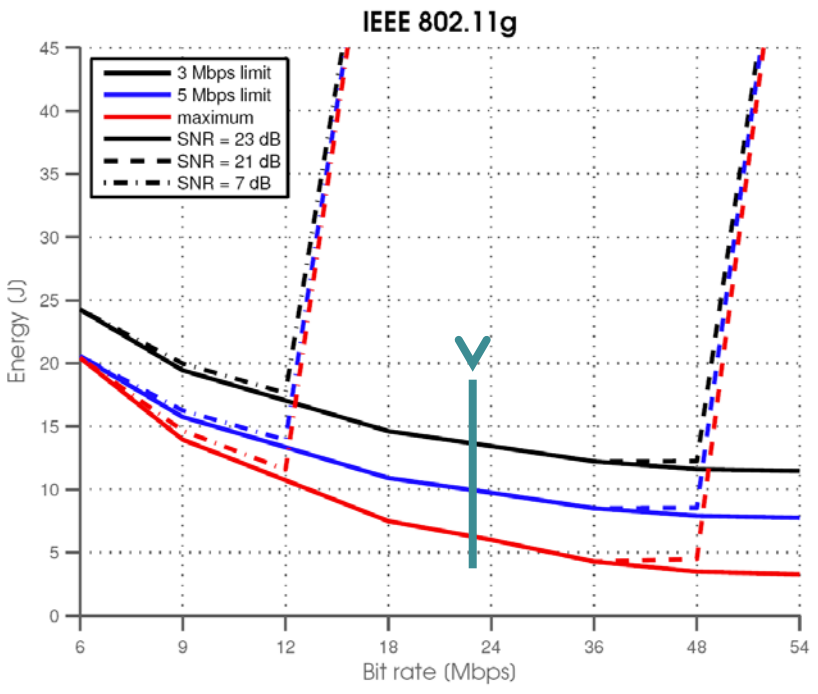
- SNR = 23 dB → no bit errors
- Lower SNR → bit errors → retransmissions



Results: Influence of data transfer rate limitation

- For different SNR values
- For bit rates higher than the limitation, energy consumption increases

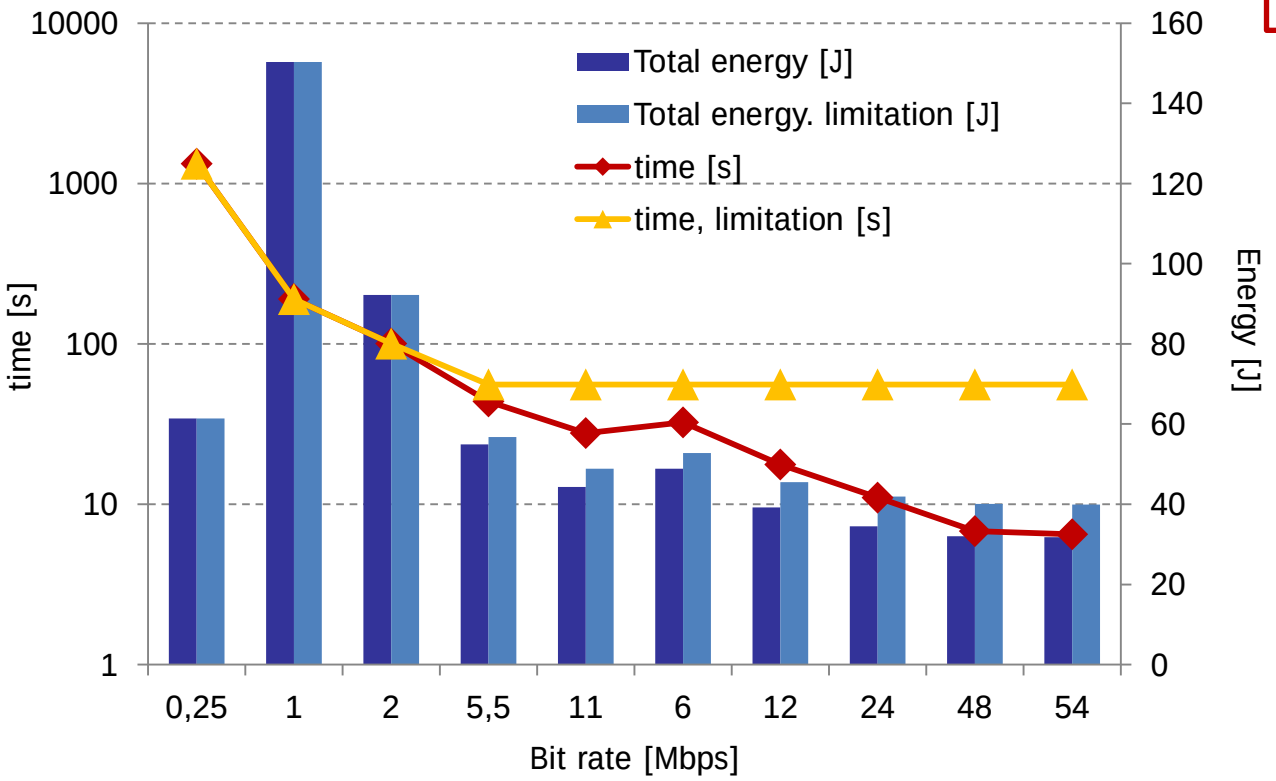




Overal system energy consumption

Energy consumption in sleep state (when not transmitting image) → significant

	Bit rate [Mbps]	unlimited data transfer rate			3 Mbps limitation		
		t [s]	E [J]	E_T [J]	t [s]	E [J]	E_T [J]
IEEE 802.15.4	0.25	1329.6	44.5	**61.4**	1329.6	44.5	**61.4**
IEEE 802.11b	1	190.4	121.9	150.3	190.4	121.9	150.3
	2	100.5	63.7	92.2	100.5	63.7	92.2
	5.5	43.8	26.4	**54.9**	55.9	28.3	**56.8**
	11	27.8	15.8	**44.3**	55.9	20.5	**48.9**
IEEE 802.11g	6	32.4	20.4	**48.9**	55.9	24.3	**52.8**
	12	17.7	10.7	**39.2**	55.9	17.1	**45.5**
	24	11	6.0	**34.5**	55.9	13.4	**41.9**
	48	6.8	3.5	**32.0**	55.9	11.6	**40.1**
	54	6.5	3.3	**31.8**	55.9	11.5	**39.9**
		200 x		2 x	23 x		1.5 x



IEEE 802.11 → transmission time reduction overcomes the high energy consumption!

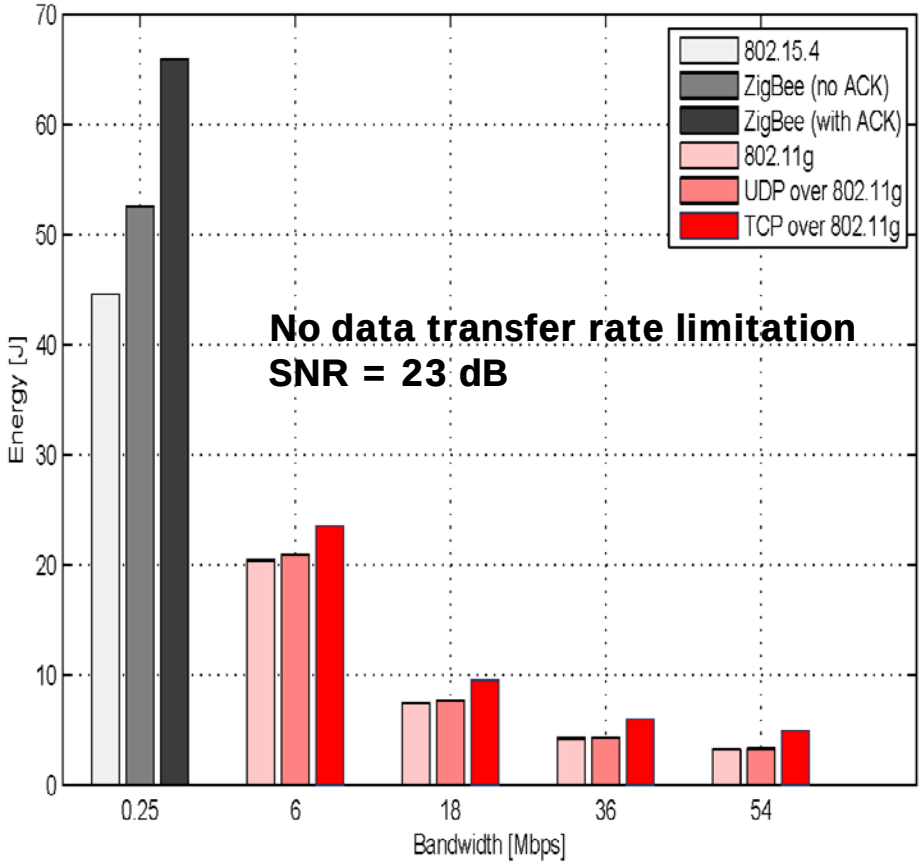
Conclusions

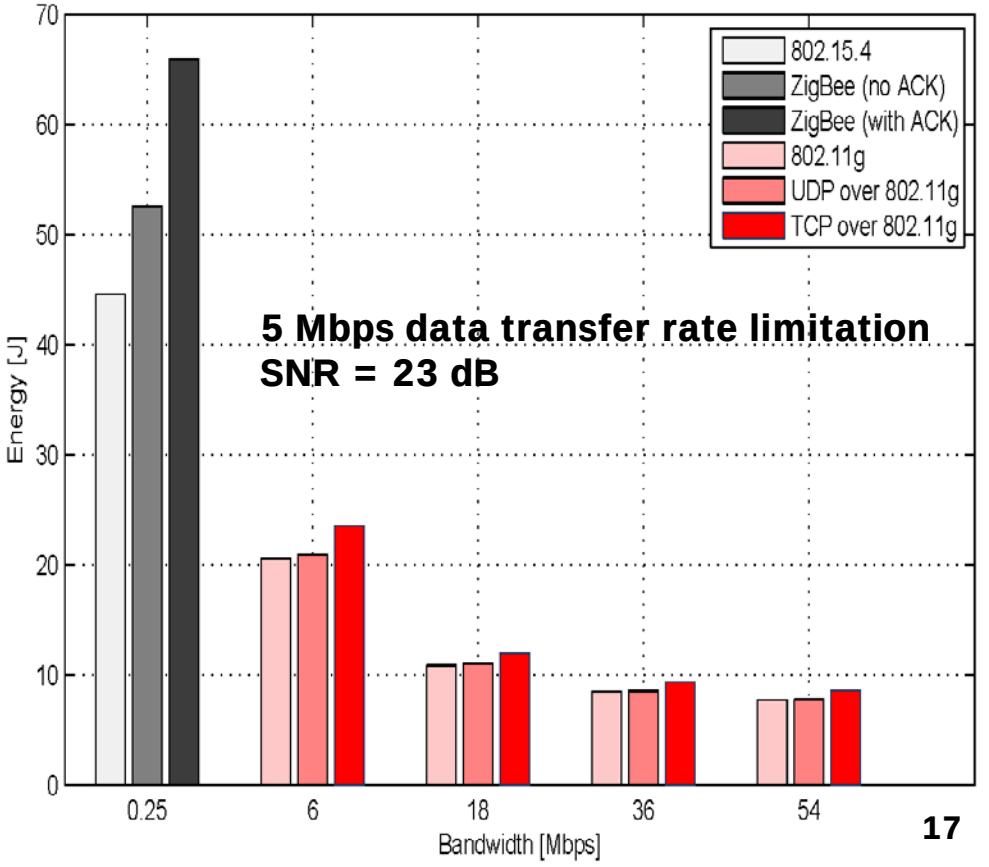
- For bit rates of 5.5 Mbps and higher → IEEE 802.11b/g is more energy-efficient than the IEEE 802.15.4
- No bit errors
  - energy-efficiency increases with bit rate increment
- Higher bit rates: errors, retransmissions → energy consumption increases
- **Compromise**: low energy consumption and reliable image transmission → 802.11b/g **intermediate** bit rates (e.g., 6 Mbps)
- Battery pack 2000 mAh, 3 V
  - IEEE 802.15.4 → 351 days
  - IEEE 802.11g (54 Mbps) → 680 days
  - IEEE 802.11g (6 Mbps) → 441 days

- Future work
  - Expand simulations with higher-level protocols
  - Estimate the expected SNR in pest monitoring system

Ongoing study: higher levels

- ZigBee – without and with ACK packet (15% and 45% energy overhead)
- UDP (no ACK) – very low overhead
- TCP (ACK) – about 20% energy overhead





Thank you for your attention!

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