Reducing The Energy Consumed During Multihop Transmissions in Wireless Sensor Networks

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The Fourteenth International Conference on Sensor Technologies and Applications
SENSORCOMM 2020
November 21, 2020 to November 25, 2020 - Valencia, Spain

Short resume of the presenter
Dr. Anne-Lena Kampen

- Received my PhD in Telematics from the Norwegian University of Science and Technology (NTNU) in 2017.
  - The research area for my PhD was Wireless Sensor Networks (WSN), and the research focus was energy efficiency and path recovery.
- I am currently an associate professor at Western Norway University of Applied Sciences (HVL)
  - Main research area is Wireless Sensor Networks (WSN),
  - Main research focus is energy efficiency.
  - Also works on embedded machine learning in combination with WSN and to some extent underwater communication
  - Teaches in subject such as advanced network communication, network security, electronics and industrial data networks.
- Leave of absence from HVL from June 2018 until Mars 2020 to work for Norwegian Research Centre AS (NORCE).
  - Mainly working on smart sensor networks - embedded machine learning, and underwater communication.
- Prior to completing PhD, I worked as a professor assistant at HVL since 2005, teaching network communication and electronics.
- Before HVL, I worked at Nera Network from 1997 until 2005 where I
  - Development and performed research on advanced electronics.
  - Specifically, the research was focused on reducing the energy consumption of power amplifiers. In addition, I developed microwave modules for radio links.
- I received my Master of Science in Applied Physics from the University of Tromsø, The Arctic University of Norway, in 1995, where my dissertation concerned microwave techniques.

The topics of research interest of our workgroup and current projects we are working on

- Energy consumption in WSNs
- Industrial Internet of Things
  - Industry 4.0
  - Delay sensitive networks
  - Condition based maintenance
  - Industrial WSN
  - Cybernetics
- Underwater Internet of Things
  - Underwater networking

Reducing The Energy Consumed During Multihop Transmissions in Wireless Sensor Networks

- Motivation:
  - Reducing energy consumption in Wireless Sensor Networks (WSN).
- Why:
  - To lengthen the network lifetime and reduce maintenance cost.

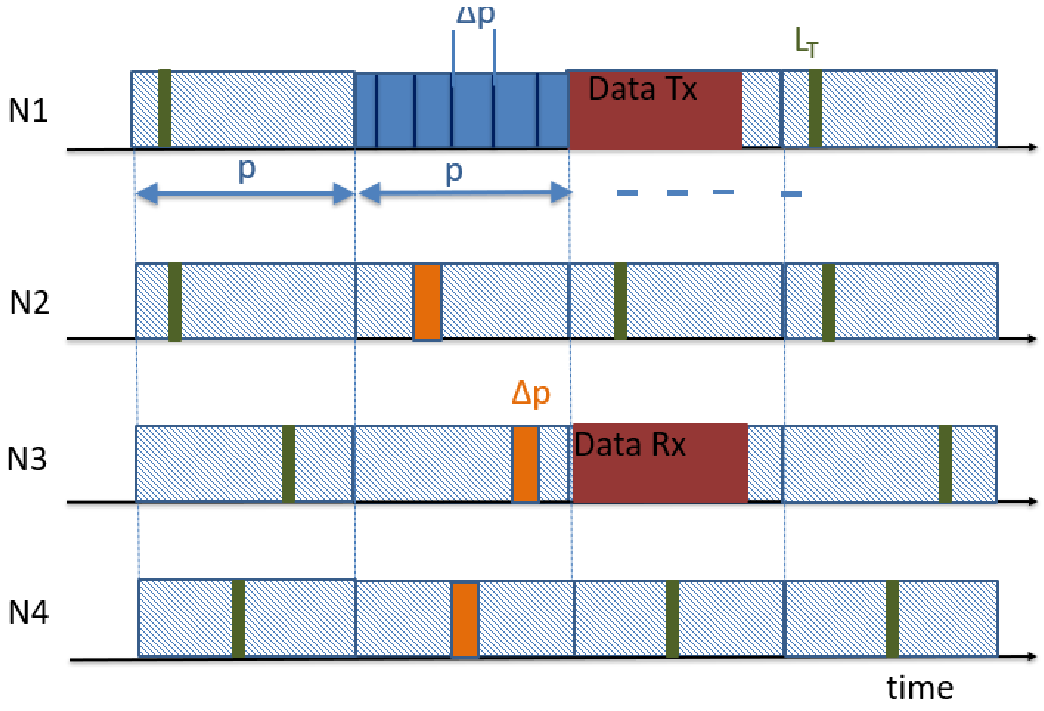
- Contribution:
  - Investigate the tradeoff between the number of re-transmissions, transmission range, the number of overhearing nodes, and number of hops in WSN to discover the energy optimal distance between consecutive nodes along the routing paths.
    - Methods applied: Analytical

  - In addition, we suggest a simple approach to reduce energy consumption of the one-hop nodes, which are most critical nodes to keep the network connected.
    - Methods applied: Analytical and simulations.

- The access protocol is Low Power Listening (LPL)

The access protocol used is Low Power Listening (LPL)

- Low Power Listening (LPL), general approach:
- Preamble-based protocol where nodes periodically wake up to listen for activity
- A preamble message is used to inform the neighboring nodes to stay awake to receive the message that is about to be sent.
- We use LPL with divided-preamble:
- The preamble divided into small fractions containing the receiver's address and the start-time for the data-packet transmission.
  - To reduce the energy consumed by the receiving nodes
  - A set of consecutive preamble-fractions, Δp, constitute the complete preamble, p, sent to signal data transmission.
- The figure illustrate the approach
  - The red squares represent a data packet that is transmitted from node N1, and received by node N3.
  - The green squares, L_T, illustrate the nodes' periodic listening for activity.
  - The orange squares illustrate that nodes receive and read a preamble-fraction.

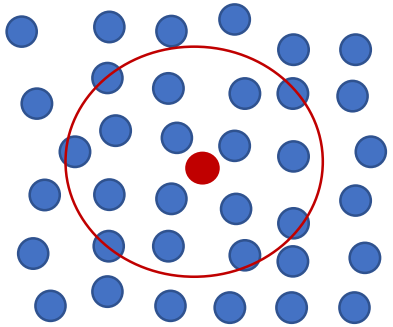


Energy consumed for each one-hop transmission along the routing paths

$$E = (k_1 + k_2 d^2)(b + p) + k_3 b + 1.5\Delta p(k_3 \pi \lambda d^2 - 1)$$

- Energy used by the sender to transmit data and preamble: $(k_1 + k_2 d^2)(b + p)$
- Energy used by the receiver to receive the data packet: $k_3 b$
- The energy that the receiver and the overhearing nodes used to receive preamble: $1.5\Delta p(k_3 \pi \lambda d^2 - 1)$
  - The number of nodes that is covered by the transmission is: $\pi \lambda d^2$
  - If a node wakes up after transmission of a preamble-fraction has started, it must remain in the receiving state until it receives the subsequent complete preamble-fraction:
    - On average, it receives one half preamble-fraction in addition to the complete fraction that it is able to read: $1.5\Delta p$
  - The transmitting node is accounted for by subtracting 1

Symbol	Meaning
k_1	Energy consumed to transmit, fixed part
k_2	Energy consumed to transmit, proportional to radiated power
k_3	Energy consumed to receive
λ	Node density
d	Transmission range
p	Preamble
b	Data packet
Δp	Preamble-fraction



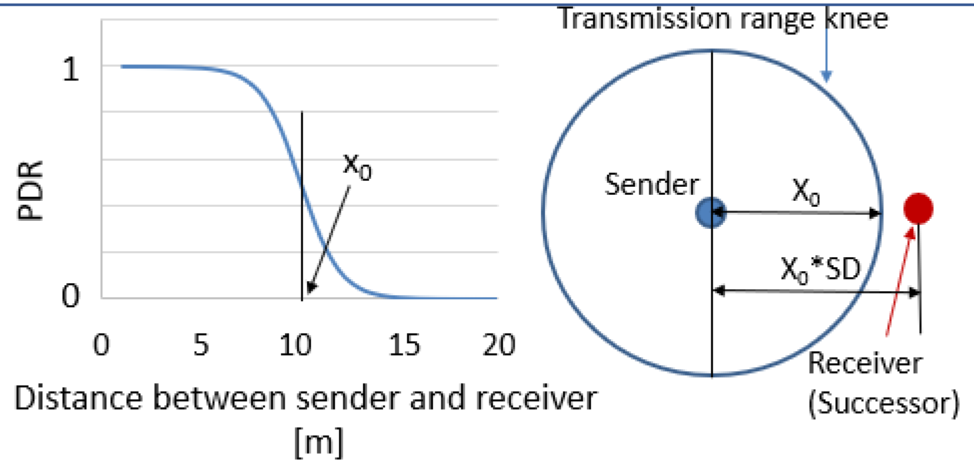
Nodes inside the red ring is covered by the transmission form the red node.

Expected number of transmission from source to sink

- A receiver experiences increasing re-transmissions when it is located at the border area of the sender's transmission range.
  - The reason is that the packet delivery rate is degrading in this area
  - To account for this border effect we use the model presented in [*] to estimate the expected number of transmissions (ETX) that is need to transmit a packet from a source to the sink along its routing path:

- $ETX[N] = \frac{1-q^m-(1-q^m)^N}{q^m(1-q)}$

- Where the packet loss rate, q is given by [*]
- $PDR(x) = \frac{1}{1+e^{\frac{x-x_0}{x_1}}} 1$



The left-hand side of the figure shows the packet delivery rate (PDR) for increasing distance between sender and receiver. Increasing the distance reduces the probability of successful delivery of packets, from PDR=1 when the distance is short, to PDR=0 for long distances. The midpoint between these two extreme PDR values is marked as $\mathbf{x_0}$, and is referred to as the knee point. The small blue circle in the center of the right-hand side figure illustrates a transmitting node, and the blue outer circle is the knee-point boarder line for the transmission. That is, for receivers located well inside the blue circle it is likely that PDR=1, and for receivers located well outside it is likely that PDR=0.

Symbol	Meaning
q	Packet loss rate
x	Distance between communicating nodes
x_0	Knee value
x_1	Border area width
N	Number of nodes along a path
m	Number of transmission trials

[*]K. Øvsthus, E. Nilsen, A.-L. Kampen, and Ø. Kure, "Modelling the Optimal Link Length in Wireless Sensor Networks for Two Different Media Access Protocols," 2015.

The energy consumed for transmitting a packet from source to sink

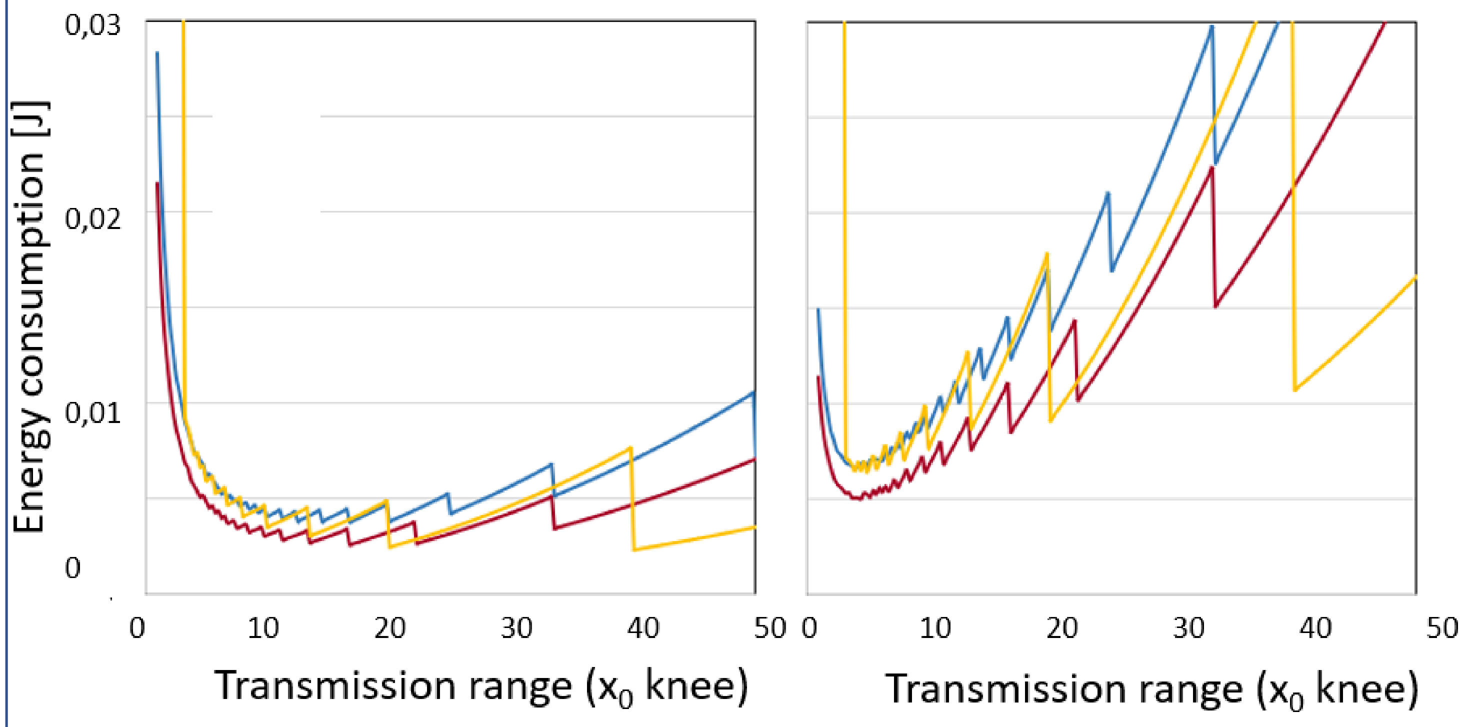
$$E = ETX[N][\ (k_1 + k_2 d^2)(b + p) + k_3 b + 1.5\Delta p(k_3 \pi \lambda d^2 - 1)]$$

- To find the total energy consumed to transmit from source to sink along the routing path:

Multiply the expected number of transmission with energy cost of each hop (presented in the preceding two slides)

Energy-optimal transmission

This figure shows the energy consumption related to transmission range analytically evaluated using the presented equations



The blue curves show the energy consumed when the distance from the sender to the receiving nodes is much shorter than the knee values (x_0), specifically $0.5 \cdot x_0$. The distance is also shorter for the red curves ($0.75 \cdot x_0$), while the distance from the sender to the receiver for the yellow curves is longer than the knee value ($1.25 x_0$).

The left-hand side of the figure shows the energy consumed when the preamble-fraction that overhearing nodes receive is 0.1 times the complete preamble.
Similarly, the figure on the right-hand side shows the results when overhearing nodes receive 0.5 times the complete preamble.

- The graphs show that energy consumption is lowest when $x_0 \cdot 0.75$ (equals ETXper-hop=1.4).
- That is, the successor nodes should be chosen so far into the border area that the ETXper-hop=1.4.

Reducing the energy consumption for the most critical nodes to keep the network connected

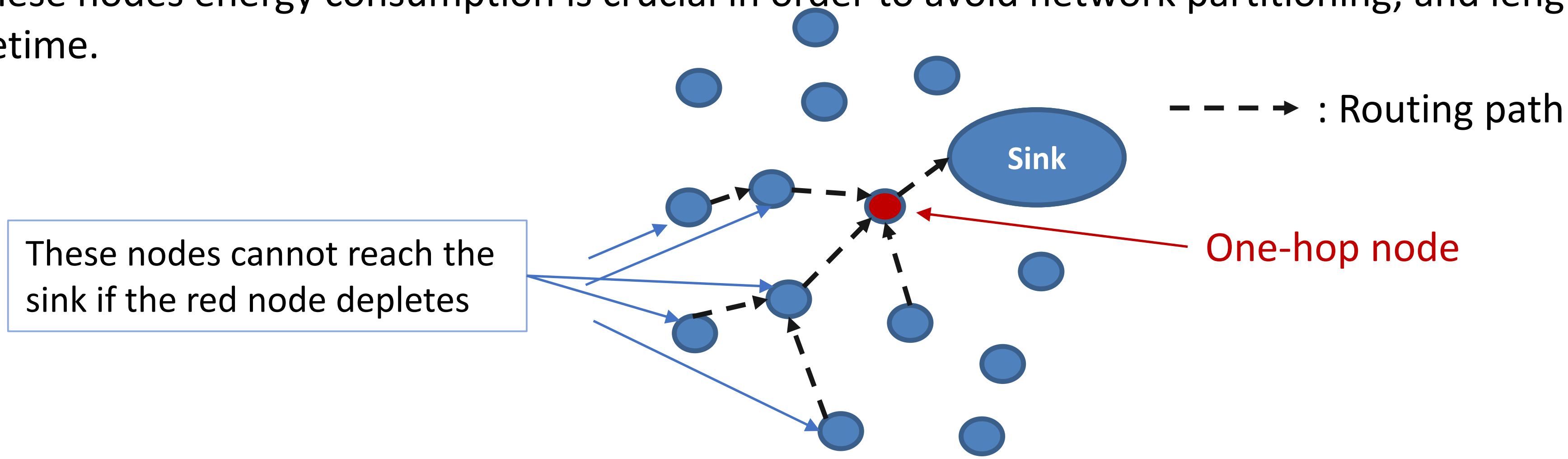
The one-hop nodes experience the highest energy-cost because they must forward packets for all the remoted located nodes.
Simultaneously, they are the most important nodes to keep the network connected.

We therefore suggest to reduce the one-hop energy consumption by :

Preventing the one-hop nodes from transmitting preamble

This is possible because messages sent from the one-hop nodes are destined to the sink, which is always active.

Reducing these nodes energy consumption is crucial in order to avoid network partitioning, and lengthen the network lifetime.



The energy consumed for a node at hop-count *h*

$$E = Tx_{nh}[\,(k_1 + k_2 d^2)(b + p)] + \; k_3(Tx_{nh} - 1) \cdot (b + 1.5\Delta p) + 1.5(\frac{Tx_{nx-1} + Tx_{nx} + Tx_{nx+1}}{3})(k_3 1.5\Delta p)$$

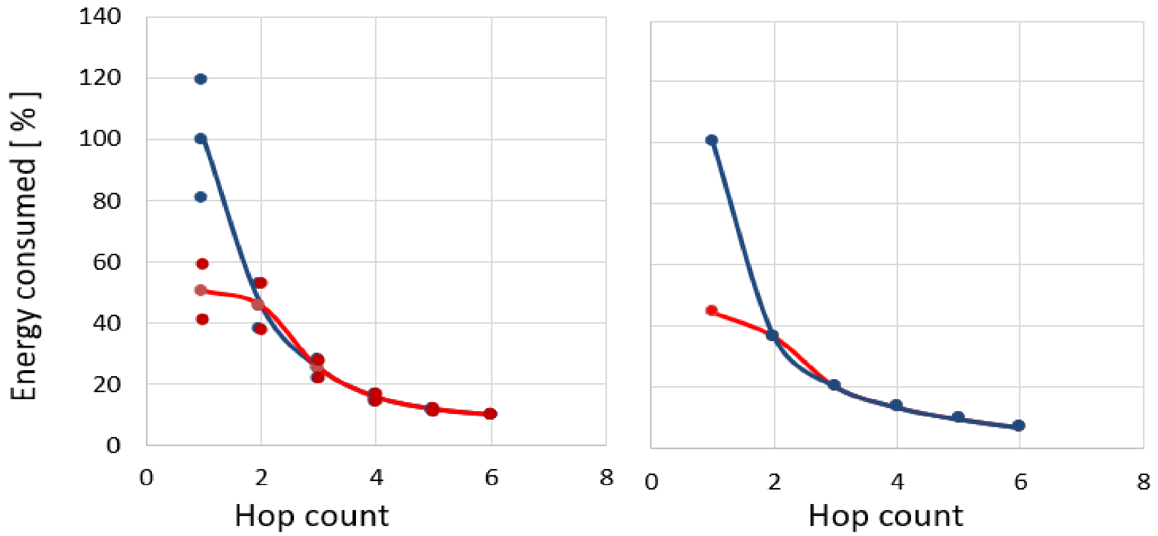
To calculate the energy consume for a node at hop-count x we must include:

- Transmit its own packet plus the for forwarding packets: $Tx_{nh}[\,(k_1+k_2d^2)(b+p)]$
  - Tx_{nh} is the total number of transmissions for a node at hop-count h.

- The energy used to receive packets for forwarding: $k_3(Tx_{nh} - 1) \cdot \; (b + 1.5\Delta p)$

- The overheard packets
  - Some of the overheard neighbors are located at the same hop-count (Tx_{nh}) while some are located at adjacent hop-count distances ($Tx_{nh\text{-}1}$ and Tx_{nh+1})
  - Each packet is received twice for nearby neighbors: once when the neighbor receives it, once when the neighbor transmits it.
    - Other neighbors’ packets are overheard only once: when the neighbor transmits it.
    - Assume that half of each overheard packet is received twice, hence, the 1.5-factor in front of the parenthesis in the last term.

Reducing the energy consumption for the most critical nodes to keep the network connected



- The blue curves show the average energy consumed when all nodes transmit preamble.
- The red curves show the average energy consumed when the one hop nodes are prevented from transmitting preamble.
- The graphs on the right- hand side show calculated results.
- The graphs on the left-hand side show simulated results, and the red marks above and below the curves represent the 95% confidence interval.

Simulated and calculated results for preventing the one-hop nodes form transmitting preamble:

- The graphs show the energy consumption for nodes at different hop-count distances from the sink.
- The energy is represented as per cent of the average value of the node with the highest consumption at each hop-count distance. (100 simulation runs with random deployment of nodes)

The graphs show that one-hop nodes' energy consumption is reduced by about 50% when the one-hop nodes are prevented from transmitting the preamble.

- To what extent the energy is reduced depends on various factors, the main being the ratio of preamble size to data-packet size.

Conclusion

- To reduce the energy consumed in multihop transmission in WSN the tradeoff between number of re-transmissions, overhearing, number of hops, and transmission range is investigated (the access protocol is LPL):

The energy consumption is lowest when the nodes to choose their successors at a distance that gives an expected number of transmissions, ETXper-hop, of approximately 1.4.

In addition:

Preventing the nodes whose successor is the sink from transmitting preamble efficiently reduces their energy consumption.

Thank you for your attention !!

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