A Harmony of Sensors

Achieving Determinism in Multi-Application Sensor Networks

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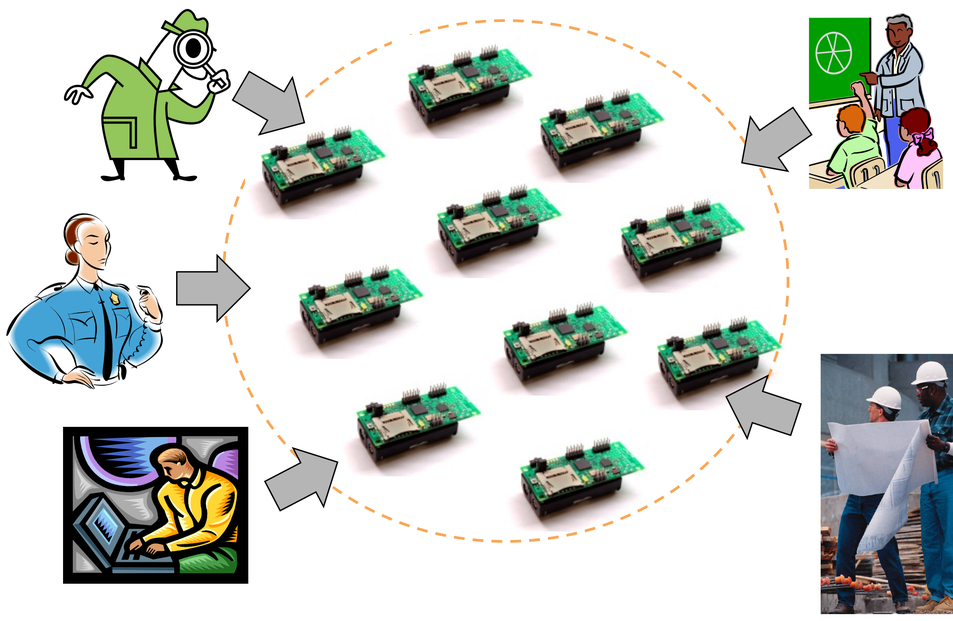
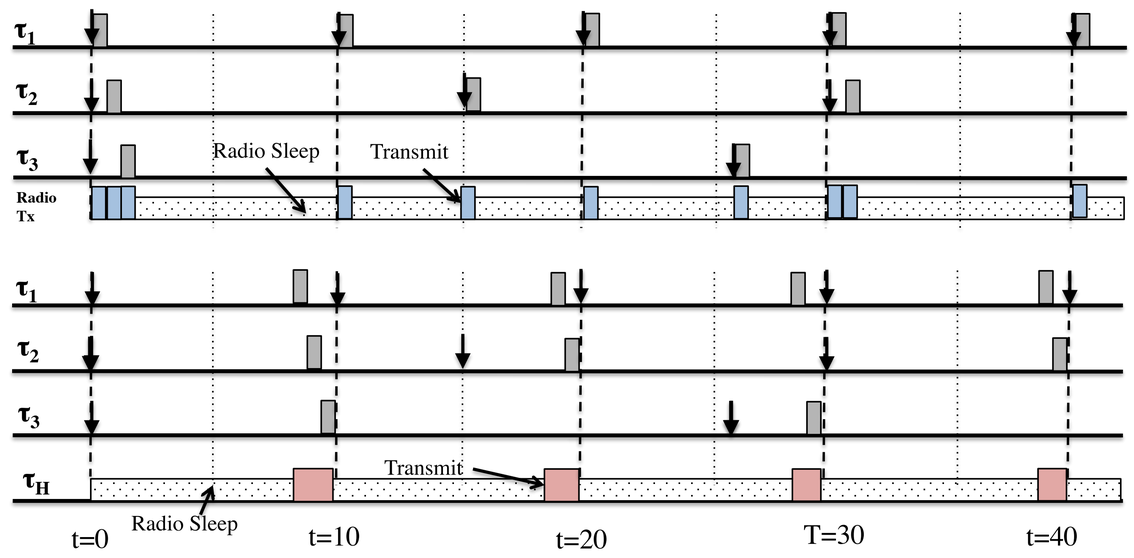
Network Behavior with Multiple Applications



- Number of *packets increase* with number of applications
- *Contention* in the network increases because of more packets
  - Energy consumption increases because of frequent radio switching
- Even multiple periodic applications can result in *aperiodic* packet behavior

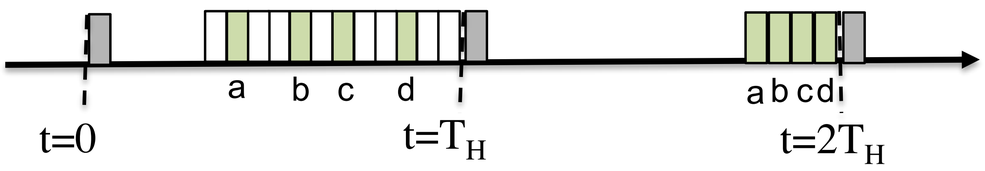
Batching Transmissions at Each Node

- Align the processor usage (or packet transmissions) along periodic boundaries of a *"Harmonizing Period"* [1]
- Helps in saving energy by reducing the switching overhead
- Facilitates the implementation of a network protocol to support better duty-cycling

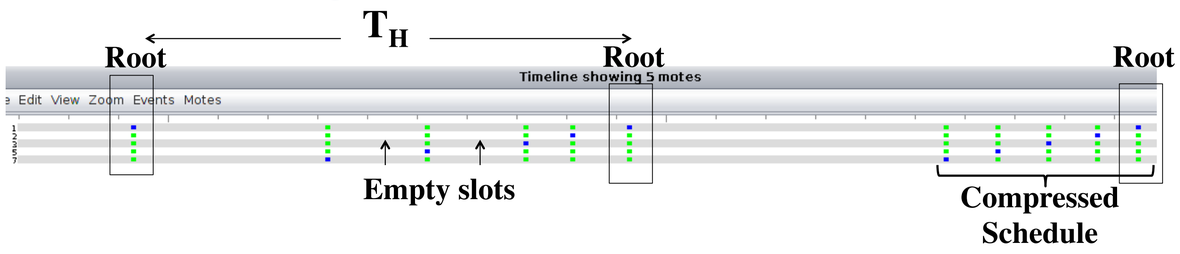


Harmonization in a Single-Broadcast Domain

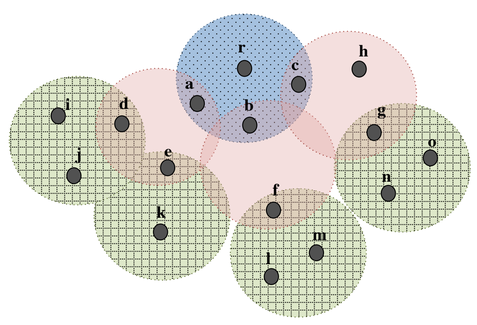
- Once the transmissions from different applications are made periodic, nodes transmit in non-overlapping slots in a distributed manner
- The root transmits a beacon at *t=0*, and all the other nodes choose a slot equal to their id
- Just *before* the start of the next cycle, nodes transmit in their slot, and listen for any empty slots
- Then the nodes autonomously compress the schedule, so that the peers and the root only need to listen *periodically*



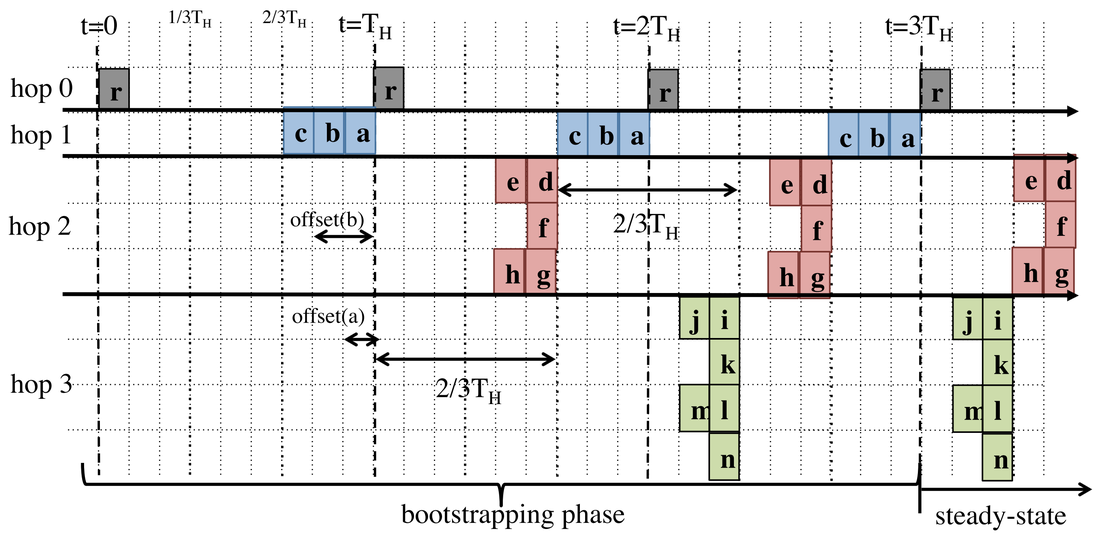
- Snapshot of protocol timeline from COOJA simulation
  - *Showing the empty slots and the compressed schedule*



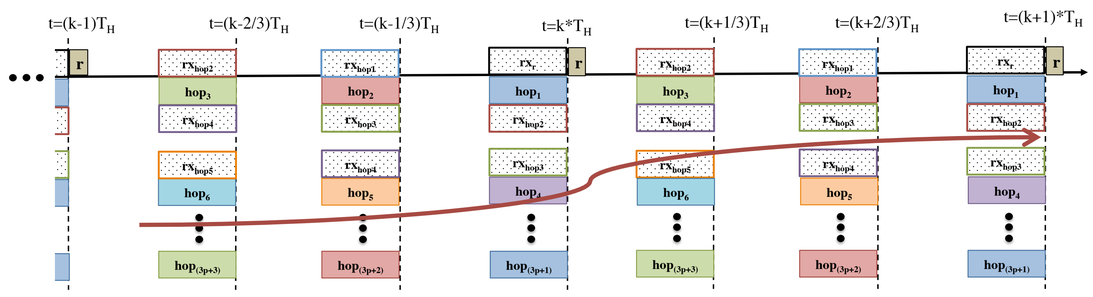
Multi-Hop NHS Protocol



- Divide the harmonizing period in equal time-slices
- Nodes at different hops use different slices
- At least 3 slices required to ensure 2 hop distance
- Children nodes transmit at $2/3*T_H$ from the parent

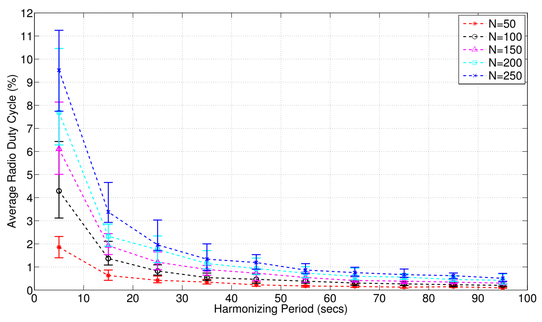


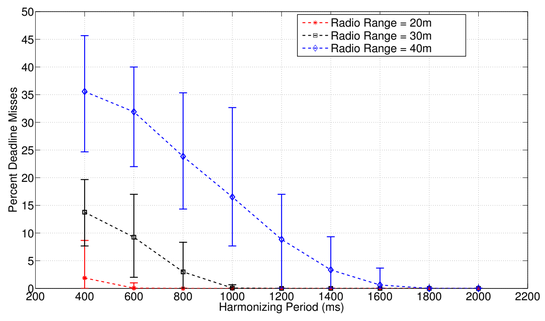
Multi-hop NHS operation in the steady state, showing the listening intervals at each hop; bold arrow shows the data collection process 6 hops spread over 2 harmonizing periods



Determinism and Energy-Efficiency

Average radio duty of all the nodes in a network of varying size with the increase in the harmonizing period





Percentage average packet drop for a network of fixed number of nodes with respect to the harmonizing period

References

[1] A. Rowe, K. Lakshmanan, H. Zhu, and R. Rajkumar, "Rate-harmonized scheduling for saving energy," in *RTSS '08: Proceedings of the 2008 Real-Time Systems Symposium*.

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