Energy Efficient Sleep/Wake Scheduling for Multi-hop Sensor Networks: Non-convexity and Approximation Algorithm

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Wireless Sensor Networks, an Overview:

- Definition: a wireless network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations.
- Application: typically involves monitoring, tracking, and controlling of a specific homogenous/heterogenous environment.
- Examples: habitat monitoring, object tracking, nuclear reactor control, fire detection, and traffic monitoring

source: wikipedia.org

WSN Special Characteristics:

- Limited power
- Ability to withstand harsh environmental conditions
- Ability to cope with node failures
- Mobility of nodes
- Heterogeneity of nodes
- Large scale of deployment
- Unattended operation

source: wikipedia.org

Sleep/Wake Scheduling Motivation

- In continuous monitoring applications (habitat monitoring, for instance), large number of sensor nodes deployed for continuous sensing and data gathering.
- Sensors *periodically* produce a small amount of data, reports to a base station.
- Idle listening by radio wastes significant amount of energy.
- Energy can be conserved by putting the radio to sleep and waking it up right before message transmission/reception.
- Usually achieved by synchronized clocks at the tranmitter and receiver nodes.

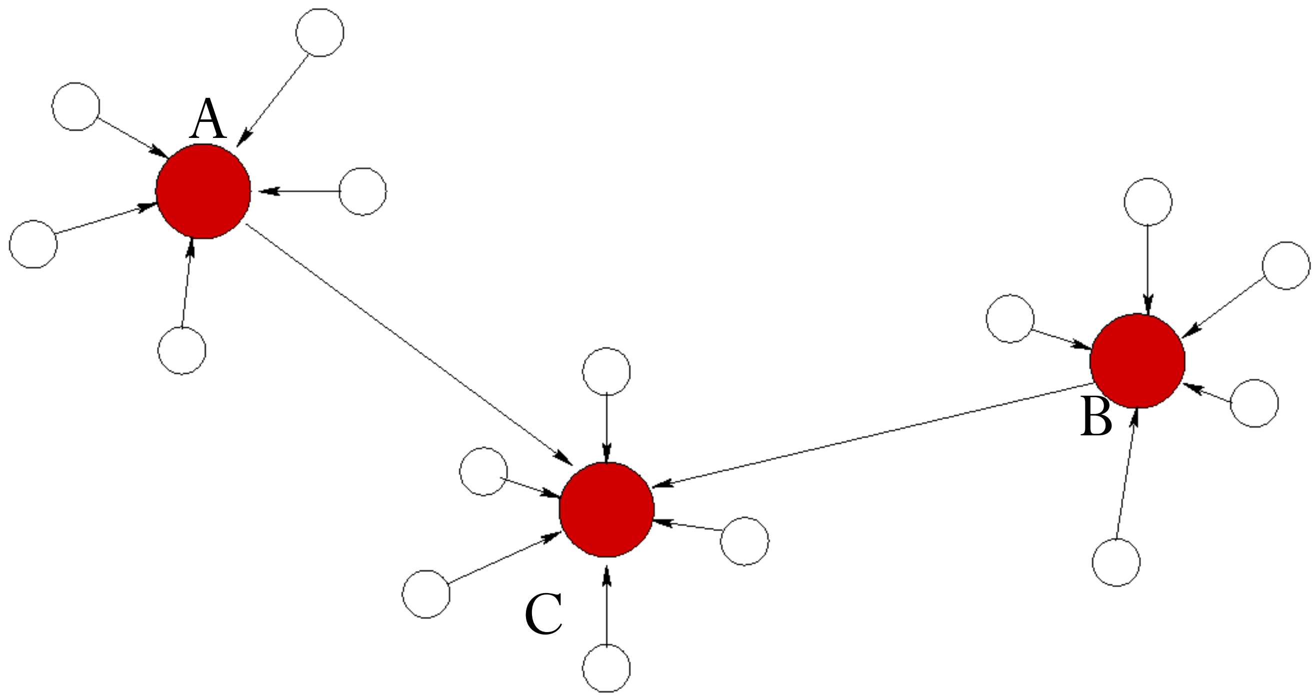
Synchronization: why is it crucial?

- Synchronization error due to *non-deterministic factors* in the system.
- Can be *Phase offset* or *Clock skew,* latter measured in ppm.
- Clock skew results from manufacturing defects, aging, temperature, pressure and voltage effects.
- Data transmission times usually of the order of milli seconds. With 5 ppm clock skew, in 5 minutes clocks drift by 1.5 ms, leading to significant errors in data communication.

System Model: Clustering

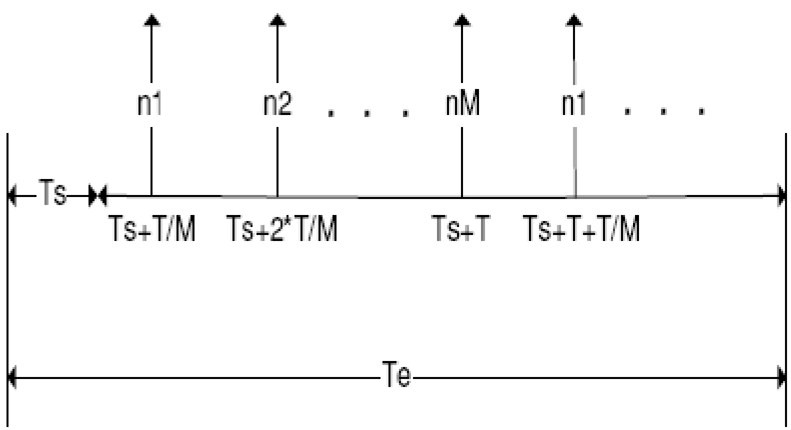
- Sensors within a geographic area are clustered together.
- Each cluster is locally managed by a Cluster Head (CH), also a sensor node. This CH is at level 1 and the reporting nodes at level 0.
- Cluster heads at level 1 report to *their* head, at level 2.
- A sensor that is a CH at level *i* is a CH at levels (i-1)…0 as well.
- CH collects data from its children, appends it with its own data, compresses this data by a factor *r*, appends it with a overhead *c* and sends the packet to the CH at the next level.

Clustering: an illustration



System Model: MAC

- Time is slotted into epochs of length T_e .
- The BS first decides the epoch when it is ready to accept data. BS informs this decision to its children.
- Each child chooses an epoch, different from the above and intimates its children to transmit data in that epoch and so on.
- Within an epoch, children transmit to their CH in a TDMA fashion, as illustrated below.



System Model: MAC

- Collision due to synchronization error: assumed to be negligible or nonexistent, citing numerical observations in low duty cycle sensor networks.
- Propagation delay: assumed to be negligible in comparison with data transmission period.

System Model: synchronization phase

- A cluster head CH, at the beginning of its scheduled epoch indexed *j*, sends N_s samples of its clock, $C(j,k)$, in real time to its children.
- Each child node *i* models its own clock value using relative clock skew and phase offset as below:

$$t_i(j,k) = a_i(j)C(j,k) + b_i(j) + e_i(j,k)$$

  where error due to non-determinism at the transmitter is also included.
- Empirical data suggests error, $e_i(j,k)$, is zero mean and normally distributed.

Synchronization error

- The child estimates the clock skew and the phase offset from the clock values in the synchronization phase.
- If τ_p is the time (in the clock of CH) when CH schedules the child to transmit, the child transmits at a time $\tau_p^{'}$ (in the clock of CH), which is shown to be normally distributed around τ_p with variance as a function of non-determinism error variance, the training data $C(j,k)$ and N_s.

Optimal Sleep/Wake scheduler

- Optimization problem formulation:

(A) Min $E = (s_p - w_p)\alpha_I Prob\{\tau'_p \notin (w_p, s_p)\} + \int_{w_p}^{s_p} \{(x - w_p)\alpha_I + \frac{L_p}{R}\alpha_r\} f_{\tau'_p}(x)dx$

such that $Prob\{\tau'_p \in (w_p, s_p)\} \geq th$,