Task Scheduling in Wireless Sensor Networks

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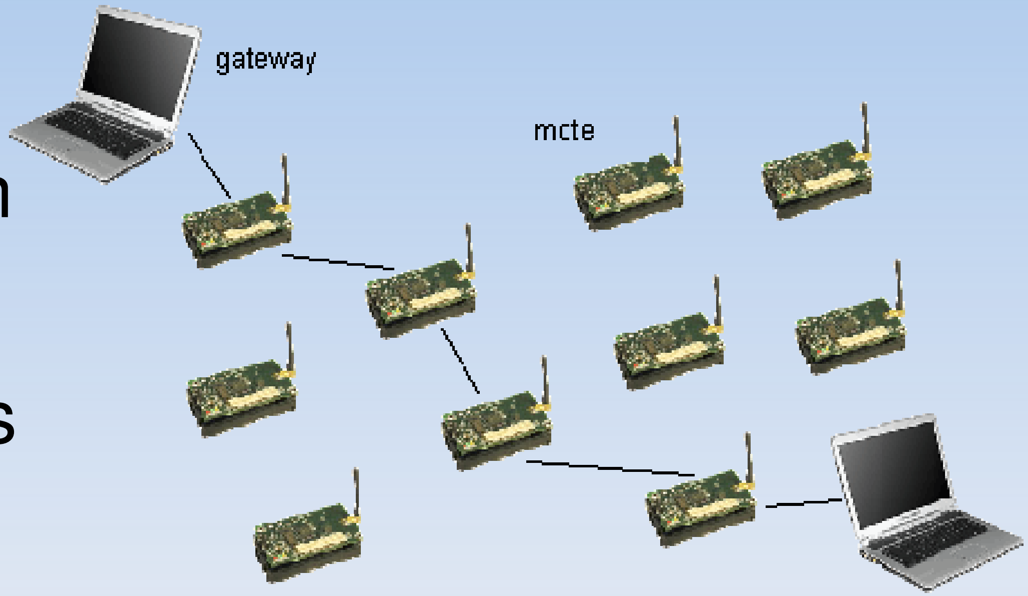
Goals

- Schedule tasks in a Wireless Sensor Network
- Tasks:
  - Form an application
  - Are repetitive
  - Have inputs/outputs
  - Are data centric
  - May be only compatible to certain types of nodes
- Schedule must also make the application as a whole to run for as long as possible



Goals(II)

- WSNs don't require a traditional scheduling problem
  - Schedule isn't for distributing a large computation over many processing nodes
  - The aim is to optimize the data flow and processing, from source to sink
  - A more appropriate scheme would control data flow by assigning tasks to certain nodes

→ Traditional scheduling algorithms are not applicable

Approach

- The schedule is in accordance with:
  - Data dependencies, as specified by a DAG (Directed Acyclic Graph)
  - Minimal network communication (to keep consumption low)
  - Task ↔ Node compatibility
- Our approach is to partition tasks from the DAG, each partition is associated with a node
- Two algorithms:
  - Polynomial, best solution – minimal communication between partitions
  - Approximative, within twice the optimal

Energy consumption in WSNs

- Dominant component is radio communication (1 CPU instruction uses 3 orders of magnitude less energy that transmitting a bit)
  - Approaches to reduce energy consumed:
    - Distance between sensors
    - The size of data transmitted
    - Radio module uptime
  - Software can only control the latter 2
    - Radio module activity is controlled by MAC layer
    - Higher level (our scheduler) is limited to minimizing the quantity of data transmitted over the network

Problem Specifics

- Our goal → Maximize Network Lifetime

$$\max_{k,\, m_k \in M} \frac{W_{m_k}}{P_{idle_{m_k}} + \sum_{i,\, v_i \in T(m_k)} \left(P_{rcv,v_i} + P_{tr,v_i}\right)}$$

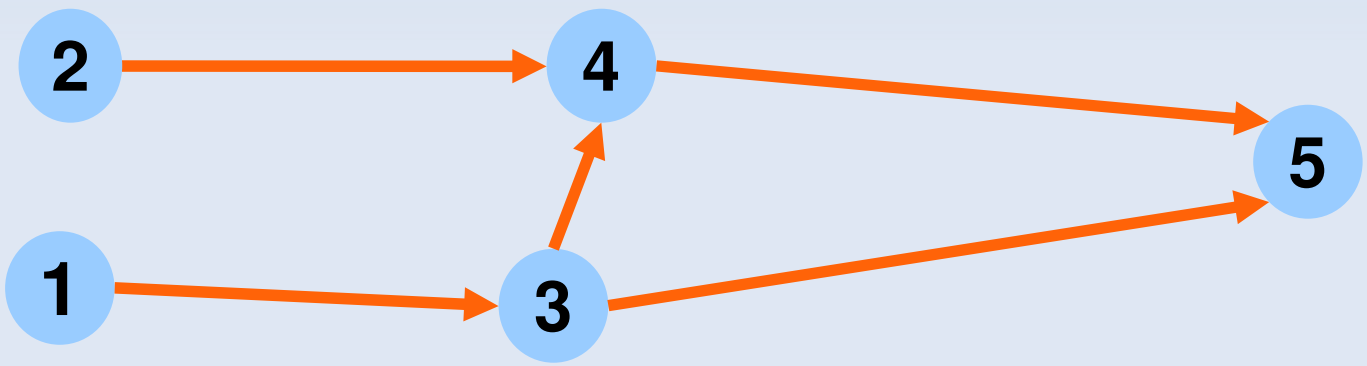
W_{m_k} – Total energy of node m_k

$P_{idle_{m_k}}$ – idle power of node m_k

$T(m_k)$ – The set of tasks allocated to node m_k

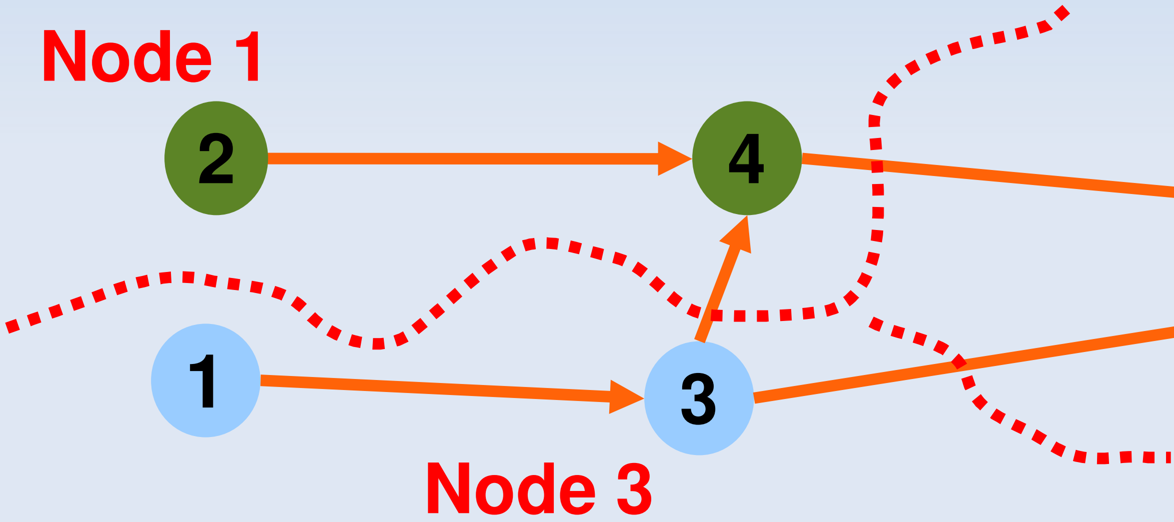
P_{rcv,v_i} – power consumed by task v_i while receiving

P_{tr,v_i} – power consumed by task v_i while transmitting



Problem Specifics (II)

- The solution → find a partitioning of the set of tasks over existing nodes that minimizes communication taking into account the other constraints



Constraints

- Minimal communication between nodes
- Task compatibility with nodes
- Multiplicity of tasks in application:
  - On only one node
  - On all compatible nodes
  - On as many nodes as necessary

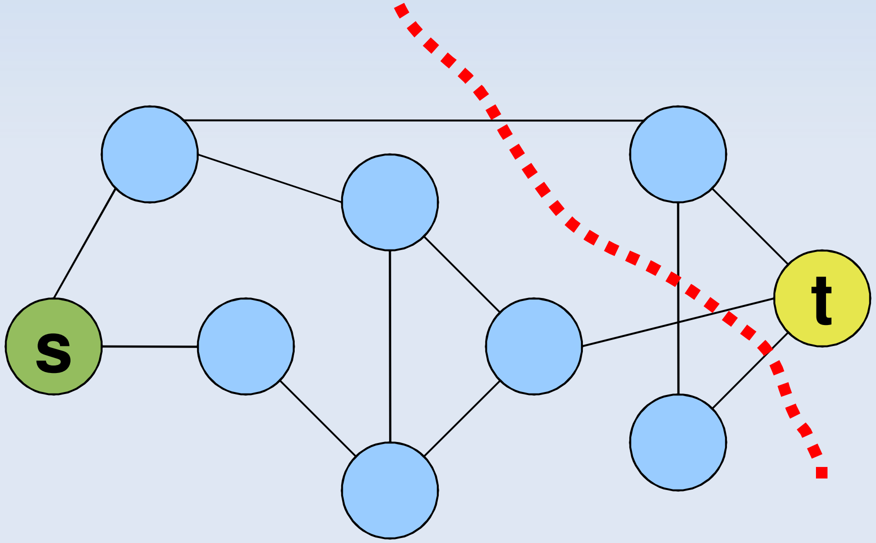
Partitioning - (s,t) Cut

- Partitioning (S,T) of a set of nodes in a graph G, such that:

$$G = \langle V, E \rangle, s \in S, t \in T, V = S \cup T, S \cap T = \emptyset$$

$$E' = \{ \langle x, y \rangle \mid \langle x, y \rangle \in E, x \in S, y \in T \}, \quad \sum_{e \in E'} w \langle x, y \rangle \text{ is minimal}$$

- Can be extended to multiple-source multiple-destination
- Equivalent to maxflux problem



Min k-cut

- Based on (s,t) cuts, with s,t as sets
  - Generates all set possibilities
    - s with k-1 elements if k is odd
    - s with k-2 otherwise
    - t with k-1 elements
  - An (s,t) is computed for each
  - The set that contains s is kept
  - The set that contains t is split into k-1 (min k-1)
- $O(n^{k^2}) \rightarrow$ polynomial, but large

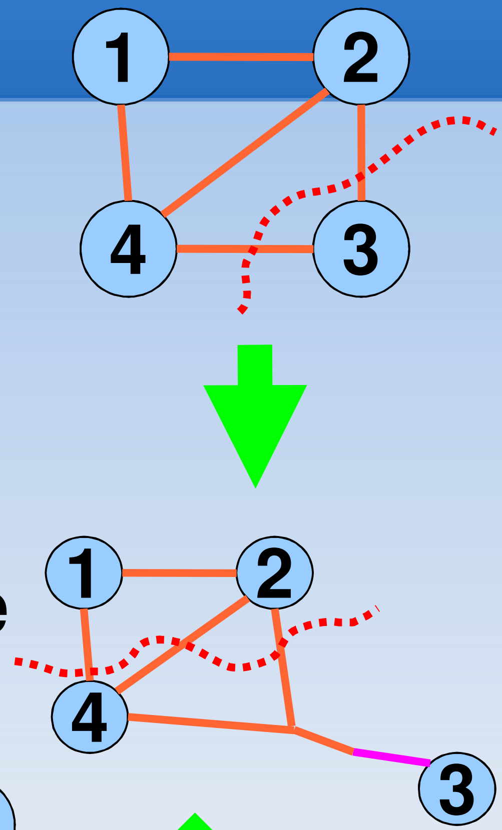
Adapted min k-cut Algorithm

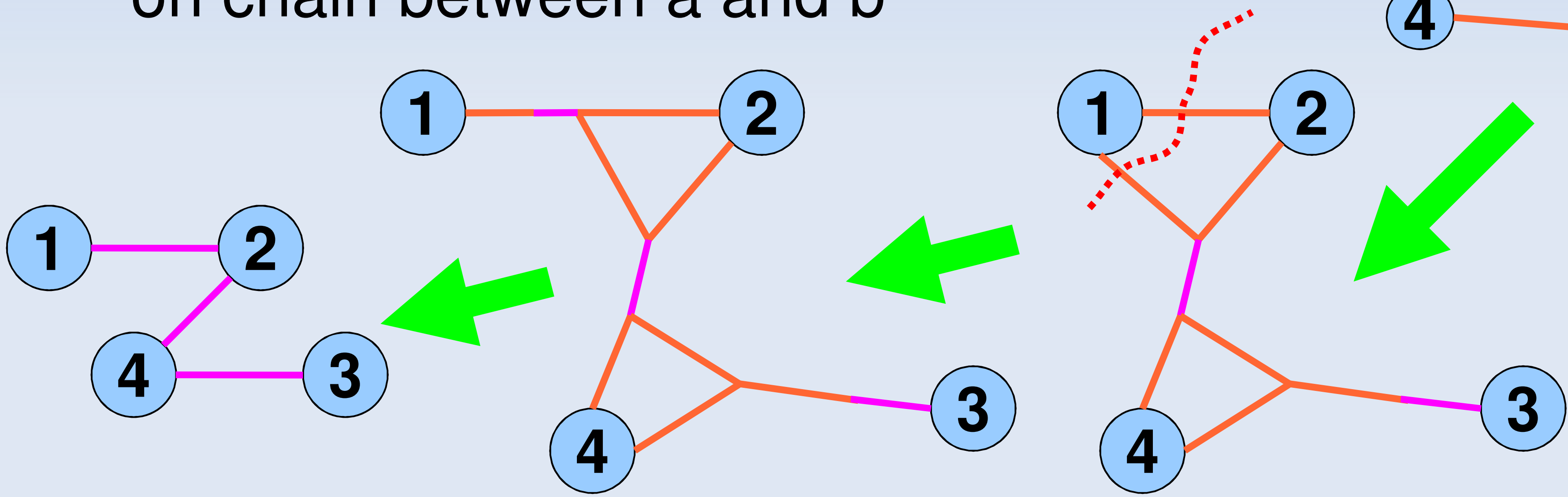
- Adaptation of Min k-cut
- Tasks with multiplicity must appear on all compatible nodes
- The set for the current component (first of the k in this recursive call) can only contain compatible tasks
- Recursive call with k-1

```
function AKCut(V,k,m_i)
if k is even then
   k' = k - 2
else
   k' = k - 1
end if
MT ← tasks that have multiplicity
V' ← V - MT
S ← the set of subsets of k' elements from V'
T → the set of subsets of k - 1 elements from V' ⋃ MT
Find s ∈ S, t ∈ T such that W(cut(s,t)) = min
/* cut(s,t) splits V into s' and t' */
/* Find the minimal cut(s,t) with maximal source set */
T(m_i) = {s'} ⋃ {v_j | v_j ∈ MT, NA(v_j, m_i) = 1}
return T(m_i) ⋃ AKCut(V-s', k-1, m_{i+1})
```

Approximation algorithm

- Gomory-Hu Trees:
  - Each edge has the weight of an (s,t) cut
- Elimination of the smallest k-1 edges
- At least k components are obtained
- (a,b) cut is the same as the smallest edge on chain between a and b





Related Work

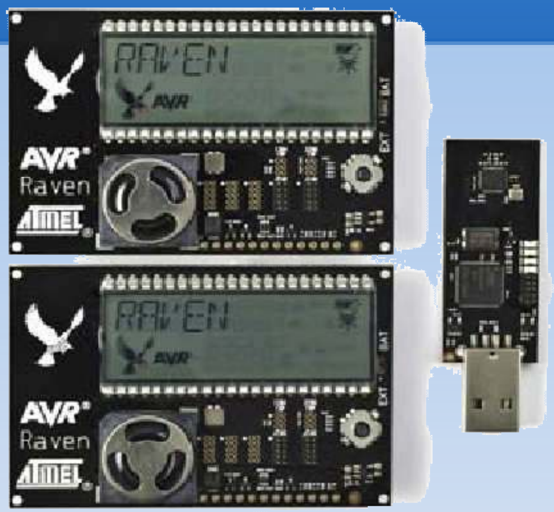
- EcoMaps

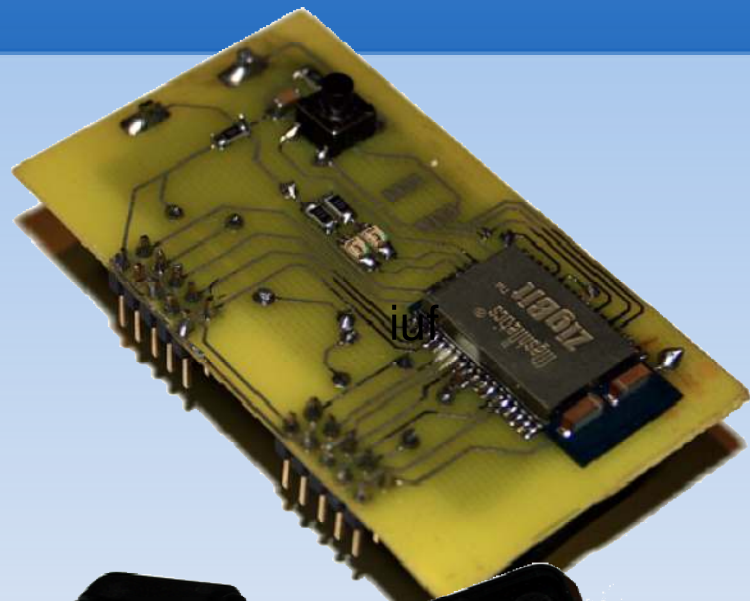
Similarities	Differences
•Application is divided into tasks •Dependencies between tasks are marked by an Acyclic Directed Dependency Graph •One of the constraints is energy	•Tasks are considered to be a part of a larger computation with a precise end, i.e. FFT •Time constraint dominates energy consumption •Simplified Communication model, with many single-hop clusters •EcoMapS solves a more traditional scheduling problem

Software Platform: Contiki

- Built for wireless sensors
- Collaborative processes
  - Based on coroutines
- uIPv6 communications stack (6lowPan)
- Communication abstractization → protosockets
- Hardware abstraction layer

Hardware Platform





Conclusions

- Dependency graph is a good model for data dependencies between tasks
- Min k-cut offers minimal communication, but is not scalable
- Approximation algorithm good for practical purposes