Computing Bridges, Articulations, and 2-Connected Components in Wireless Sensor Networks

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Wireless Sensor Networks

Definition (WSN)

Wireless sensor networks are networks of many small, battery-powered, resource-constrained devices equipped with sensors and transceivers embedded in a physical environment operating unattendedly for long periods of time

Challenges:

- Ad hoc deployment
- Resource limitations
- Communication is main energy consumer
- Consumption grows with lengths of messages
- Non-homogeneous energy consumption leads to disconnectness

Motivation

- Topology depends on weather interference, multi-path fading, transmit power, antenna direction
- Articulations may become hot spots (**Example 1**)
- k-connected networks achieve high degree of fault-tolerance
- Connectivity can be increased by increasing transmit power
- But: High transmission power leads to more interference and higher consumption of energy
- Algorithm Ramanathan et al. (**Example 2**)

Articulations and 2-Connected Components

- Algorithm needs to know articulations
- Benefits:
  - Clustering (**Example**)
  - Backbones (CDS computation)
  - Replication techniques
  - Sleeping modes
  - TDMA schemes
- How to compute articulations in a WSN?
- Classical algorithm by Tarjan is based on depth-first search

Distributed Depth-First Search

- Pass token through network
- Do not pass token to node already visited (**Example 3**)
- Algorithm not suitable for WSNs (**Example 4a, Example 4b**)
- Problems: Unknown message delays, message duplication, no FIFO order
- Algorithm of Cidon and correction by Tsin
- Which computational model is realistic for WSNs?

Computational Model

- Nodes have no global knowledge about network
- No two nodes in network share memory
- *At least once* semantics of message delivering (realization: ARQ)
- Messages are not corrupted (realization: error-correcting codes & ARQ)
- Every message eventually reaches its receiver
- No *FIFO order* for message delivery
- Every node is aware of all its links
- Nodes have unique identifiers

Computing Articulations

- Tarjans algorithm is based on *low values*
- Low value is minimum of
  1. depth of node,
  2. low values of sons of node, and
  3. depth of nodes reachable via back-edges from node
- **Challenge**: Compute low values of nodes and mark components without additional messages or long messages for proposed computational model
- Procedure:
  1. Forward and Visited messages carry depth
  2. Backtrack messages carry low value
- Basic principle (**Example 5**)
- Problems with this approach (**Example 6**)

Algorithm

- Labeling 2-connected components (Example 7)
- Complexity:
  - At most $4m$ messages of length $O(\lg n)$
  - $2m + n - 1$ messages in best case
  - Messages: 3 Bits for identifier + integer (not all messages)
  - $2n + d - 2$ units of time in worst case (d depth of tree)
  - Low memory footprint
- Better than currently known algorithms
- Implemented on real sensor network

Related Work

- Hohberg: $2m + n - 1$ messages of length $O(\lg n)$, $2m + n - 1$ units of time
- Chaudhuri: FIFO-order $O(n)$ messages of length $O(n)$
- Swaminathan et al.: Incremental distributed algorithm for computing the 2-connected components in a dynamically changing graph (too complex for WSN)
- Karaata: Self-stabilizing algorithm for finding articulations

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