FlexiTP – A Flexible schedule based TDMA Protocol for Fault Tolerant and Energy Efficient Wireless Sensor Networks

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Why another MAC protocol?

- End-to-end guarantee on data delivery
- Self-healing as network dynamics change
- Energy saving

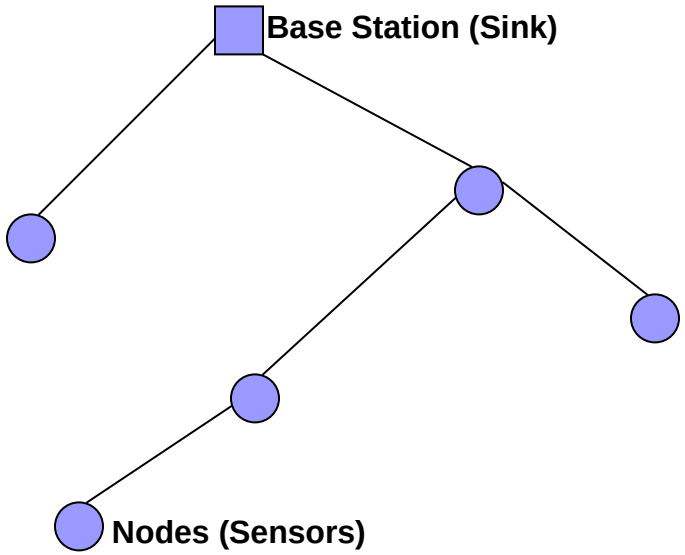
Difficulties:

- Resource constraints of the node
- Hostile environments

TDMA protocol in WSN

- Guarantee collision free communication
- Reduce idle listening
- Challenges:
  - Determining collision-free slots for all nodes
  - Overheads in setting up a network schedule
  - Time synchronization between nodes
  - Network dynamics

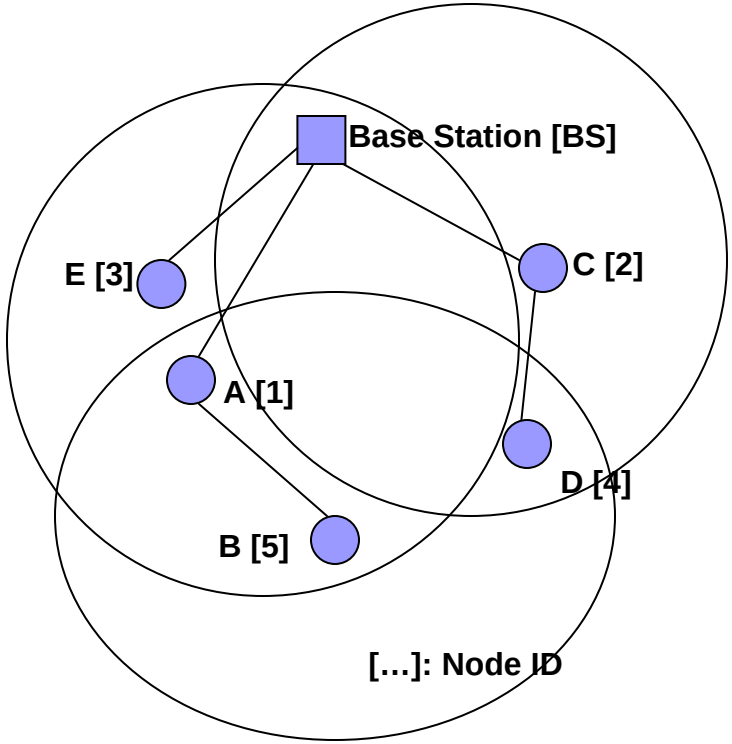
Deployment Scenario



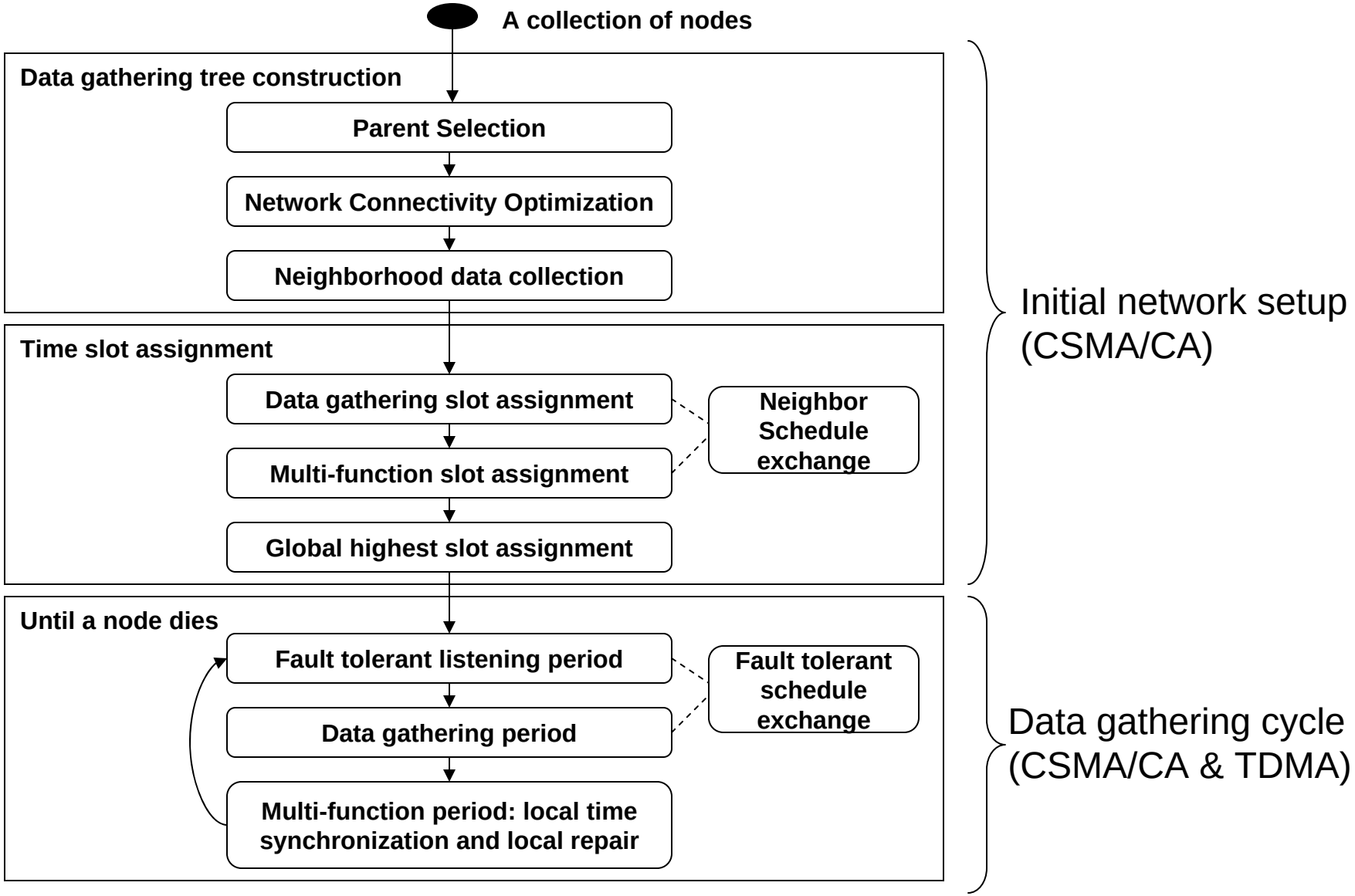
- Designed for a static ad hoc network (Location of nodes are almost always the same)
- Nodes may join, leave (temporarily) or die at any time

Terminology

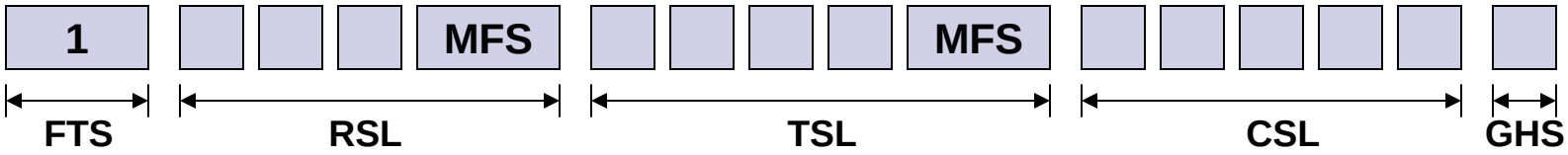
- Parent
- Child
- Ancestor
- Descendant
- First level neighbor
- Second level neighbor



FlexiTP Protocol Overview

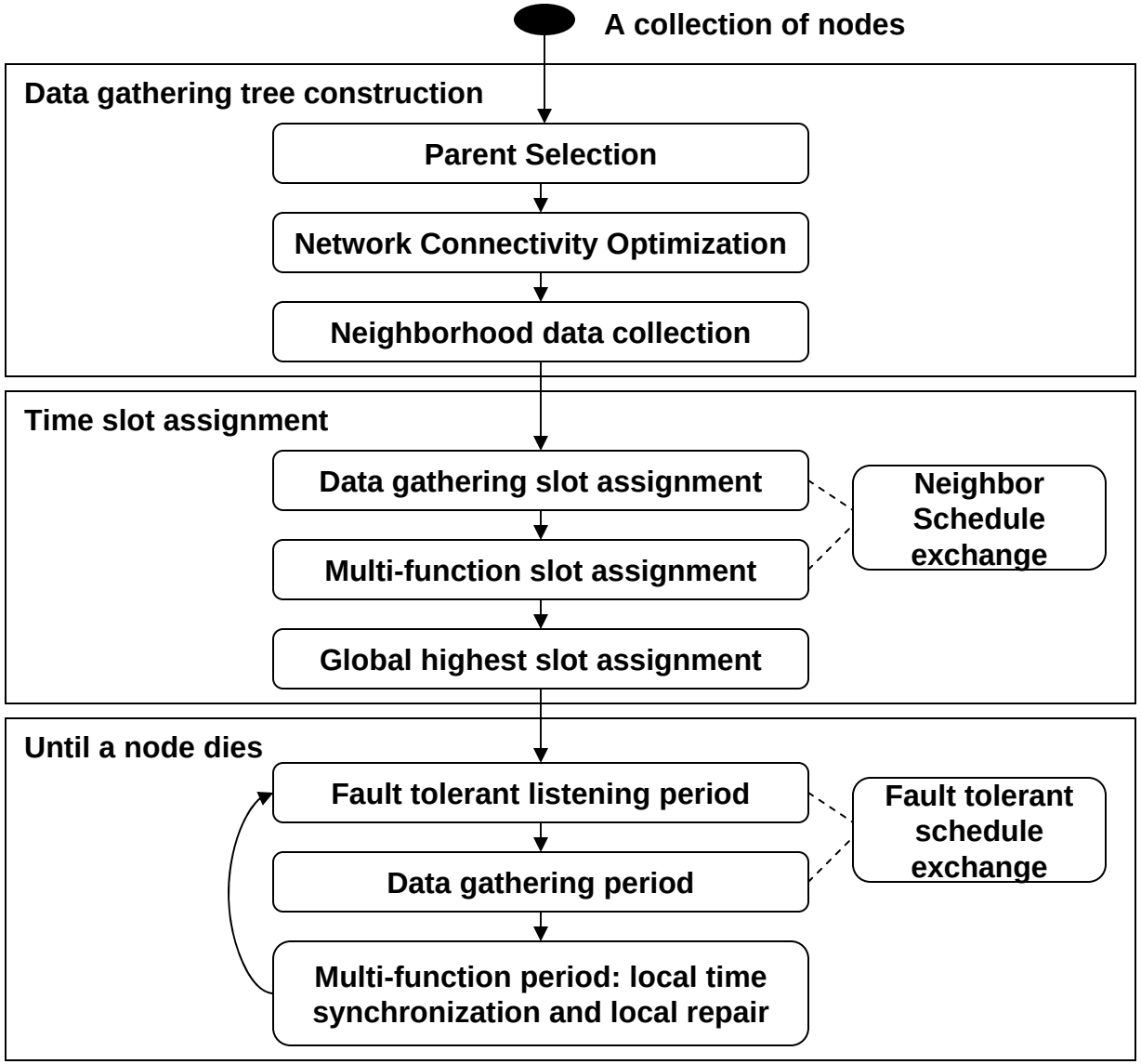


Node Schedule

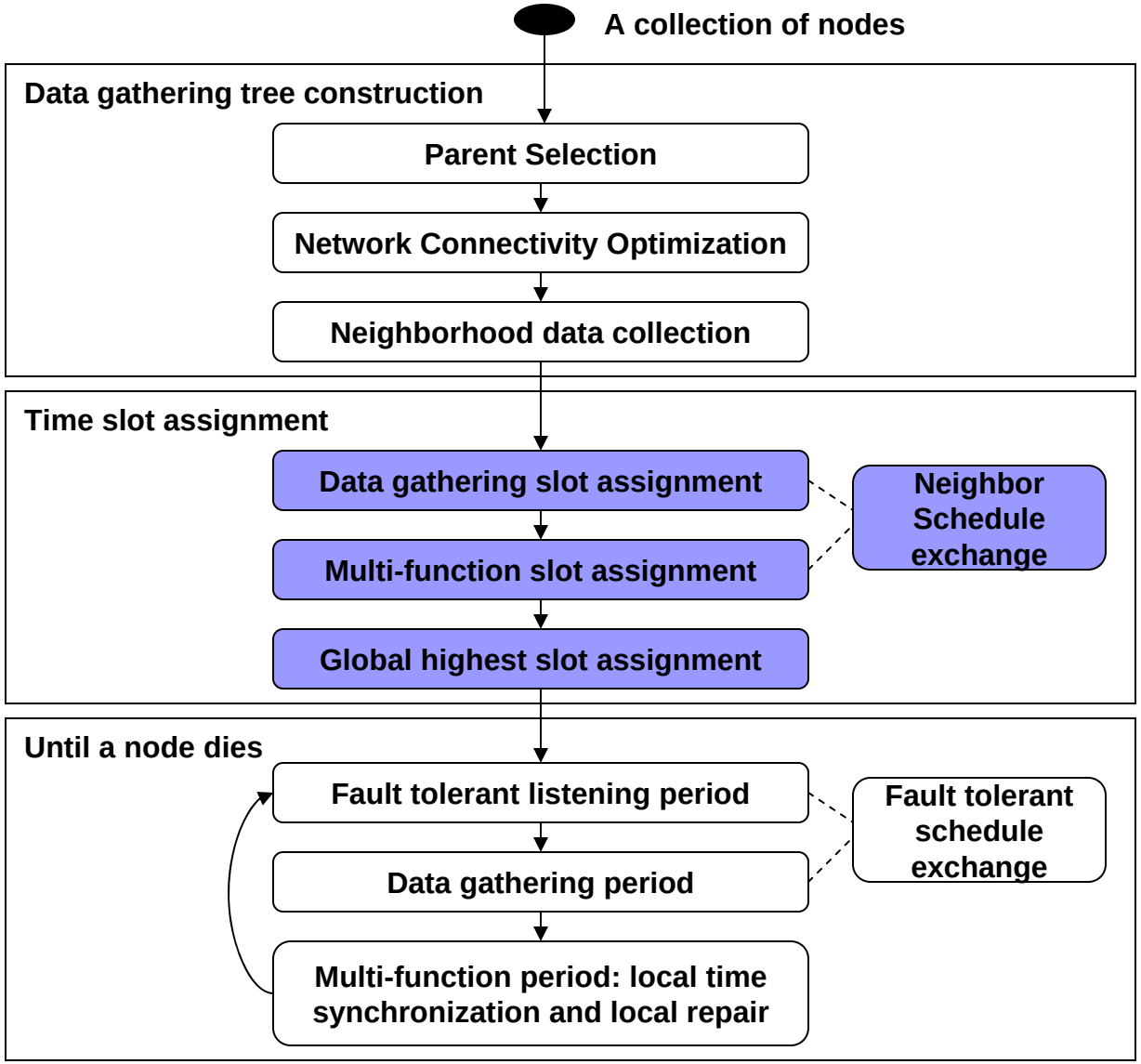


- Fault Tolerant Slot (FTS): A short CSMA period where all nodes listen & adjust to local neighborhood state
- Receive Slot List (RSL): Receive mode in node's scheduled slot
- Transmit Slot List (TSL): Transmit mode in node's scheduled slot
- Multifunction Slot (MFS): Local time synchronization
- Conflict Slot List (CSL): Records slots that conflict with 1st and 2nd level neighbors
- Global Highest Slot (GHS): Network's highest slot number

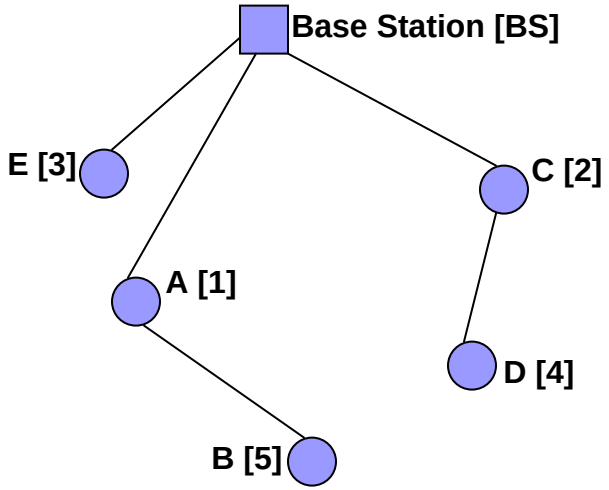
Data gathering tree construction



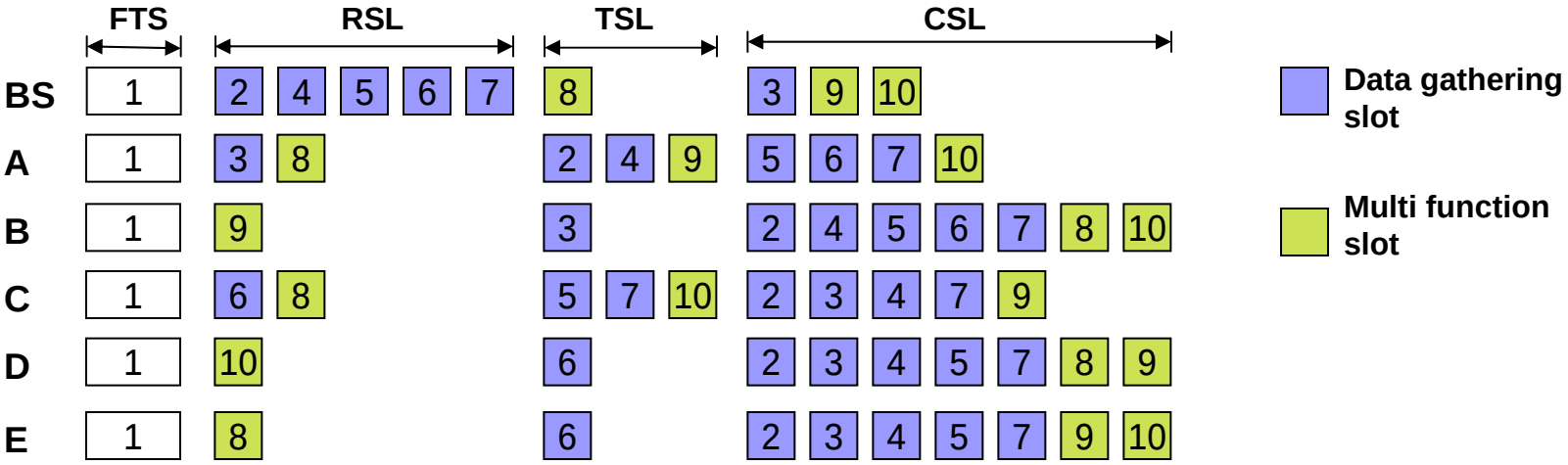
Time Slot Assignment



Time Slot Assignment Example



[…]: Node ID



Time Slot Assignment (1)

- Four phases:
  - Data gathering slot assignment
    - Each node selects an unused slot to transmit
    - Routers on path to BS assign slots in RSL & TSL
  - Neighbor Schedule Exchange
    - Propagates the claimed slot its first-level and second-level neighbors

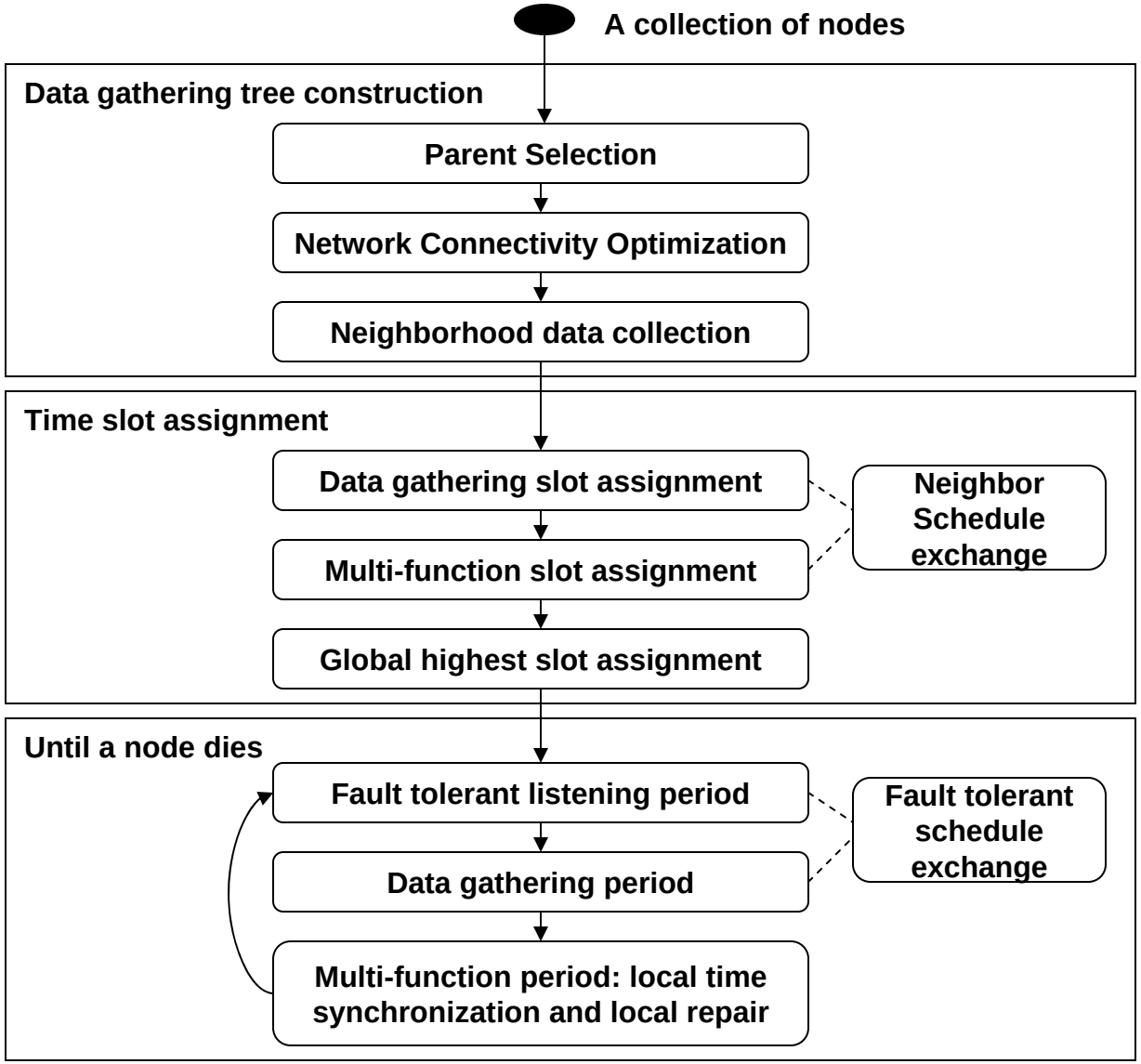
Time Slot Assignment (2)

- MFS assignment
  - Top down, DFS technique
  - BS generates a token and claims an MFS slot
  - This slot is bigger than any slot in RSL & TSL
  - Neighbor schedule exchange is performed
- GHS assignment
  - After MFS is completed, the BS knows the highest slot claimed by any node
  - DFS token passing scheme to inform GHS to all nodes

Time Synchronization Scheme

- Time synchronization is local – each parent synchronizes with its children
- In MFS, node broadcasts its clock and GHS
- Simple & effective with low overheads
  - Sync. message piggybacked with MFS
- Slot lengths adjusted to radio-switching times
- A fall-out node can easily resynchronize by listening to neighbors' transmissions

Data gathering cycles



Fault tolerance – Packet loss

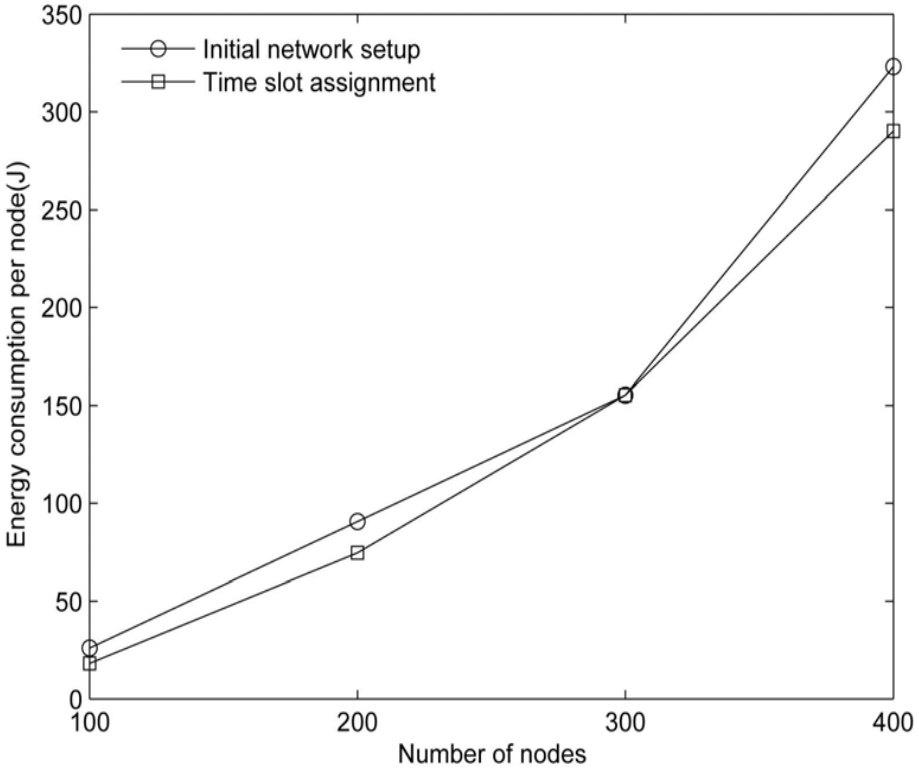
- During setup phase, RTS/CTS/ACK of IEEE 802.11 is used
- In data gathering cycles, packet loss is detected based on RSL
  - If a node does not receive its child's data in a slot, it requests retransmission in MFS
  - Child should send the data in its next slot
  - If child receives multiple retransmission requests, it searches for a new parent

Fault tolerance – Dead & New nodes

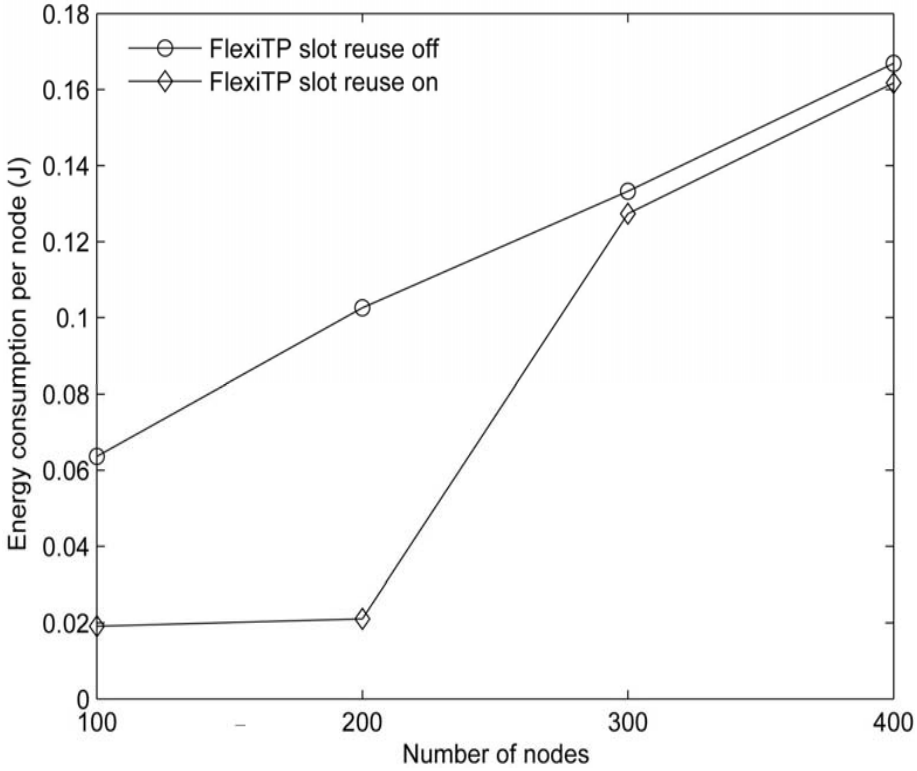
- Death of nodes:
  - Child dead if no data received in two cycles
  - Parent dead if no MFS received in two cycles
- Joining of new nodes:
  - New node sends distress signal in FTS
  - Based on responses, builds table and chooses a parent
  - Parent assigns slots; claimed slots informed in fault-tolerant schedule exchange

Energy efficiency

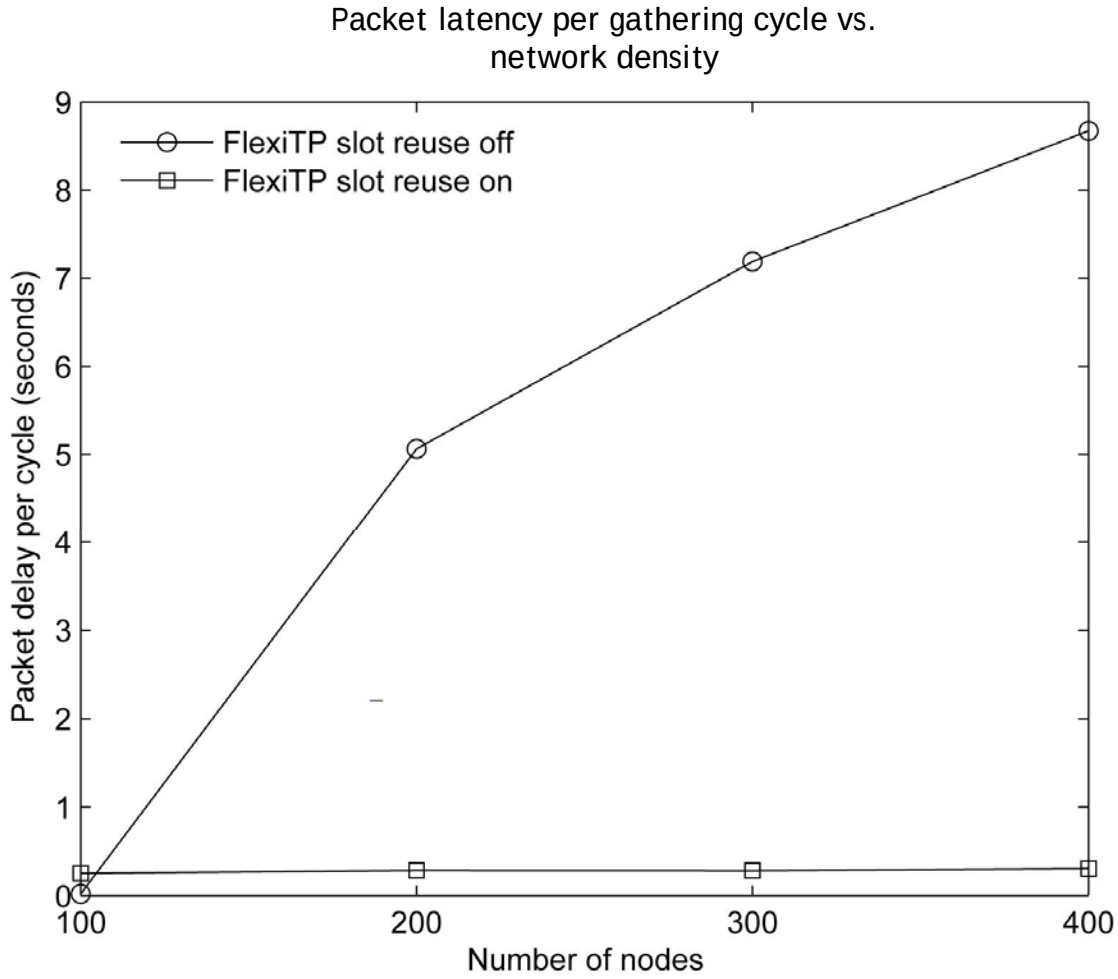
Network setup energy per node vs. network density



Node energy consumption per data gathering cycle vs. network density



End-to-end packet delay



Conclusion

- Flexible slot structure
- Nodes are active only in their schedules
- Low latency in data transfer
- Time synchronization is done *locally*
- Fault tolerance for network dynamics
- Suited for periodic gathering sensor networks where nodes are almost static