# Efficient TDMA Algorithm for Energy Harvesting Wireless Sensor Networks

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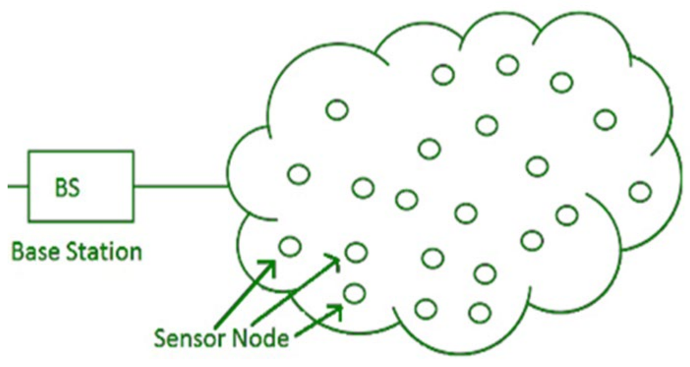
## Wireless Sensor Networks (WSNs)

- A set of nodes that monitor, collect, and relay data to a base station.
- Application Examples:
  - Health Monitoring
  - Military
  - Agriculture

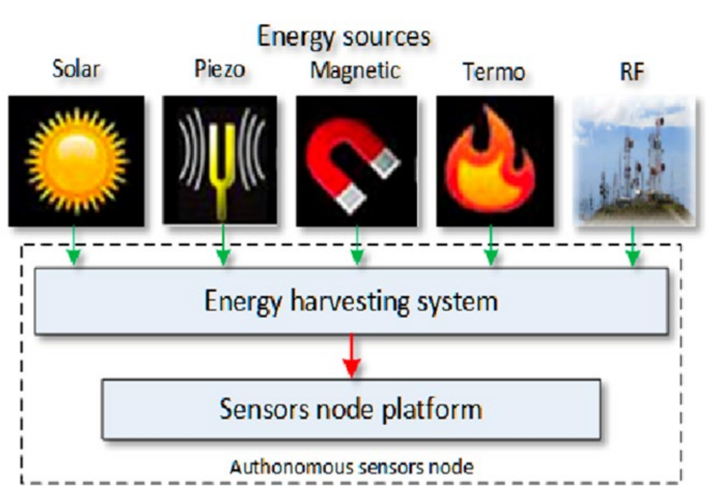



## Limitations of WSNs

- Very small nodes, thus:
  - Limited lifetime of batteries
  - Inability to replace batteries
  - Difficult/expensive to maintain

## Energy Harvesting

- Energy harvesting is a possible solution.




## Research Problem

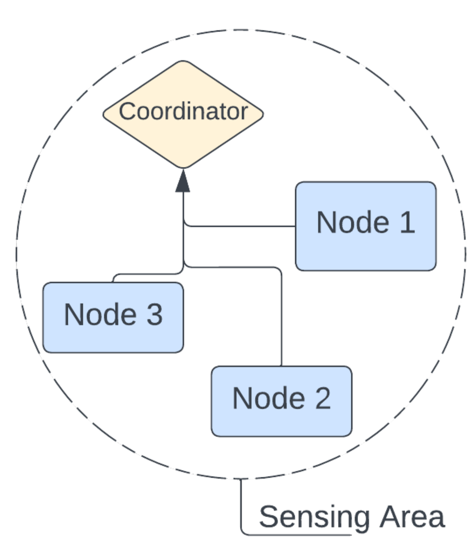
- Energy harvesting is a stochastic process.
- All WSN protocols require redesign to accommodate for inconsistent energy availability.
- Time Division Multiple Access (TMDA) is one of these protocols.

## Research Objective

- To design an energy and latency efficient TDMA algorithm which handles the effects of clock drift.

## System Model

- A single-hop network as in [1].
- Coordinator acts as a central node.
- Each node has a unique ID.
- Only nodes are energy harvesting.
- Harvest-store-spend policy is used.




## Proposed Solution

- The coordinator coordinates the synchronization and transmissions of the nodes.
- The coordinator initially syncs the network using a sync message.
- The coordinator monitors the network for any errors. An error is defined as: all sensor nodes are out of energy or a transmission overlap (due to clock drift).
- The coordinator resyncs the network if an error is detected.
- If a sensor node is out of energy, it can resync based on another node that previously transmitted.

## References

1. Kosunalp, Selahattin. (2016). EH-TDMA: A TDMA-Based MAC Protocol for Energy-Harvesting Wireless Sensor Networks. International Journal of Computer Science and Information Security. 14. 325-328.
2. X. Qi, K. Wang, D. Yue, L. Shu, Y. Liu and H. Zhao, "Adaptive TDMA-based MAC protocol in energy harvesting wireless body area network for mobile health," IECON 2015 - 41st Annual Conference of the IEEE Industrial Electronics Society, Yokohama, Japan, 2015, pp. 004175-004180, doi: 10.1109/IECON.2015.7392751.
3. Rivero-Angeles ME. Quantum-based wireless sensor networks: A review and open questions. International Journal of Distributed Sensor Networks. 2021;17(10). doi:10.1177/15501477211052210

## Proposed Algorithm

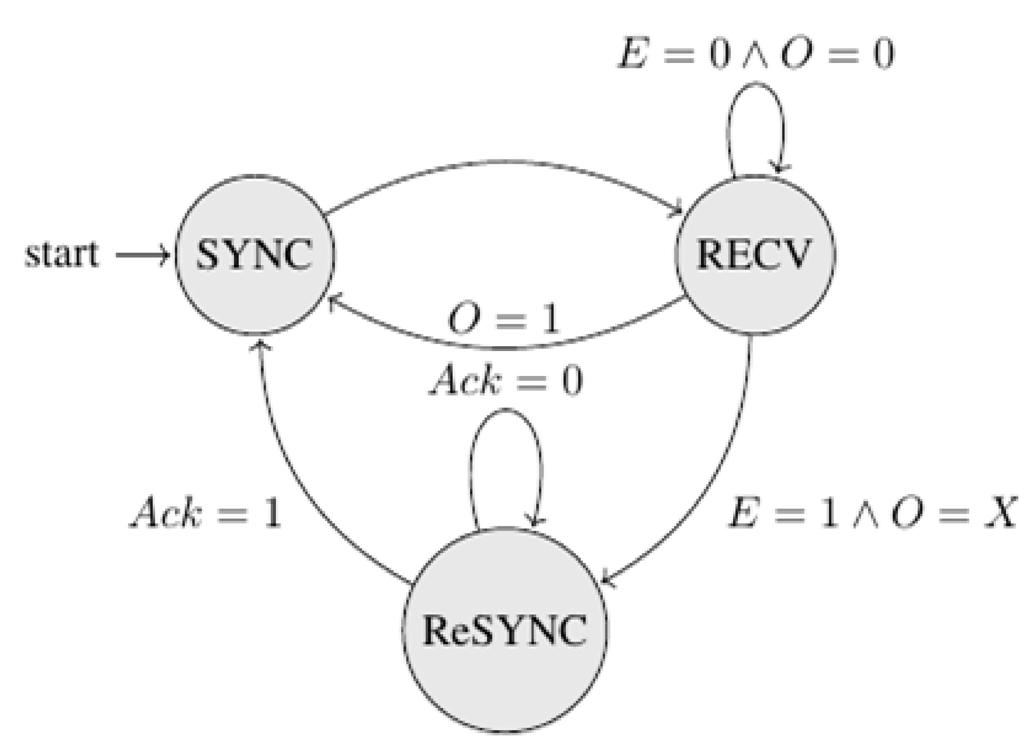
**Algorithm 1:** Coordinator Pseudo Code

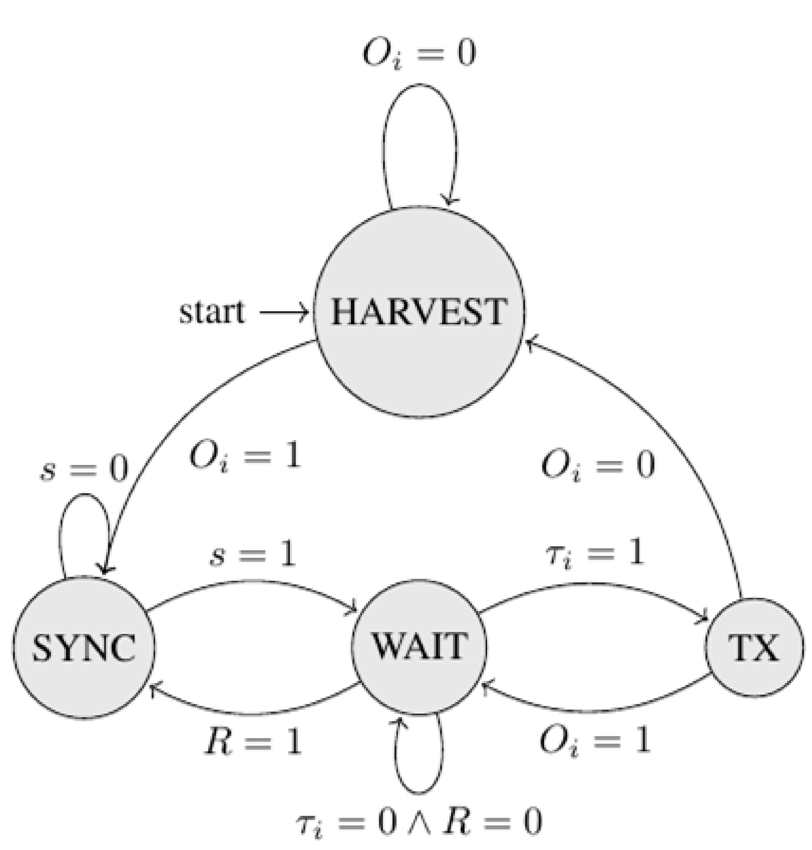
```
begin
    switch phase do
        case SYNC do
            transmit SYNC packet;
            set phase to ACTIVE;
        end
        case ACTIVE do
            recieve packets;
            check for errors;
            if overlap detected then
                halt network by broadcasting RESYNC
                  packet;
                wait for an acknowledgement;
                if acknowledgement received then
                    set phase to SYNC;
                end
            end
            if out-of-energy detected then
                set phase to SYNC;
            end
        end
    end
end
```

**Algorithm 2:** Sensor Node Pseudo Code

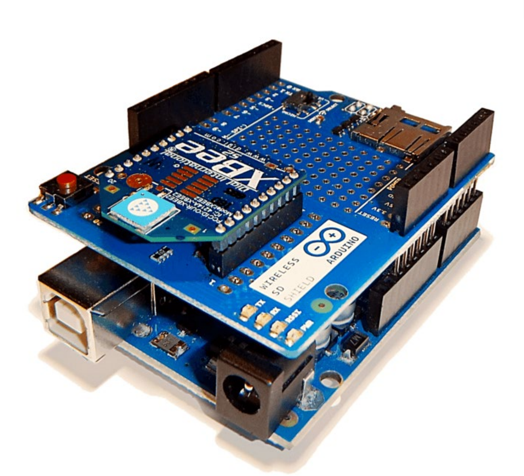
```
begin
    switch phase do
        case DEAD do
            harvest energy;
            if sufficient energy collected then
                set phase to SYNC;
            end
        end
        case SYNC do
            wait for a packet;
            if packet recieved then
                set phase to ACTIVE;
            end
        end
        case ACTIVE do
            if coordinator SYNC then
                wait (ID_C − 1)t_s seconds;
            end
            if other node SYNC then
                wait (ID_C − ID_R) mod N)t_s seconds;
            end
            send packet;
            if still has sufficient energy then
                remain in ACTIVE phase;
            else
                set phase to DEAD;
            end
            if recieve a RESYNC packet then
                send acknowledgement;
                set phase to SYNC;
            end
        end
    end
end
```

## Proposed Algorithm Implementation




## Experimental Setup



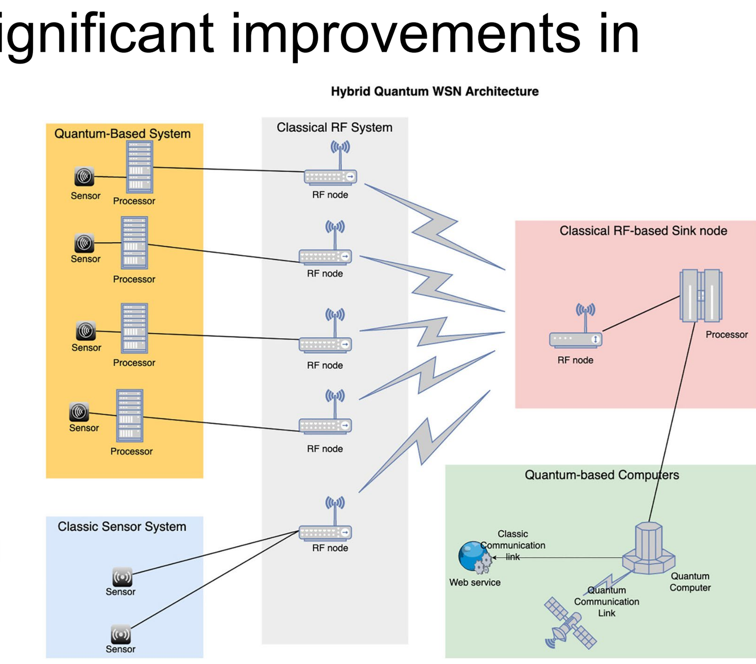
- A node is comprised of an Arduino Uno and an XBee RF module.
- Energy harvesting is modeled as the Bernoulli process.

## Results

- The proposed algorithm achieves a latency of 56 ms compared to 4.6 s which is achieved by [1].
- Preliminary energy calculations show significant improvements in energy consumption.

## Quantum Science Applications

- A hybrid quantum communication system which uses an array of RF wireless sensor nodes as an intermediate to a quantum link [3].
- The RF nodes can harvest energy from an RF station.




## Possible Research Areas

- How can the data sensing (transmission data) rate be optimized based on the energy harvesting rate or vice-versa?
- Assuming RF nodes are equipped with data buffers, how long should data remain in the buffer before they are removed?

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