SMART ANTENNAS FOR IoT NETWORKS

Improving Synchronization Time in 6TiSCH Networks with Smart Antennas

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Introduction & Motivation

- IETF 6TiSCH schedules time-slot and frequency-channel resources to build reliable, low-power, low-latency IoT networks.
- Smart/directional antennas boost performance further — longer range and reduced interference by focusing energy in a chosen direction.
- But narrow antenna coverage makes network synchronization and neighbor discovery much harder than with omnidirectional antennas.
- This study proposes a new 6TiSCH message packet and mechanism letting nodes discover neighbors before full network synchronization.

WHY IT MATTERS

25–75 nodes tested across density scenarios

~25% faster sync with scanning packets

2 antenna types compared: omnidirectional vs. rotating

Background

1

Smart / ESPAR Antennas

Electronically Steerable Parasitic Array Radiator antennas adjust radiation direction electronically, reducing interference and collisions in dense IoT deployments.

2

6TiSCH Protocol Stack

Uses Time-Slotted Channel Hopping (TSCH) for stable, low-power, low-latency medium access — achieving over 99% packet delivery in ideal conditions.

3

Two-Phase Network Formation

(1) Enhanced Beacon (EB) messages synchronize nodes to the network; (2) DIO messages build the routing tree (DODAG).

4

The Directional Antenna Challenge

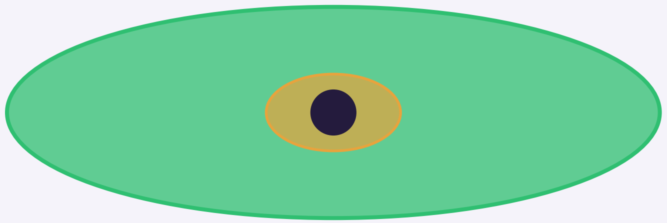
Narrow beam coverage means nodes must repeat neighbor-discovery steps across many directions — far slower than with omnidirectional antennas.

Modeling the Antenna Radiation Pattern

- Cooja's radio model was extended to account for each node's antenna orientation, not just inter-node distance.
- +5 dBi gain in the antenna's facing direction; −15 dBi loss in the opposite direction.
- Result: ~30 m range in the facing direction vs. ~40 m of interference protection from unwanted directions.
- Signal strength (RSS) follows a log-distance path-loss model incorporating inter-node distance and relative antenna angles:

$$RSS = P\_TX + P\_PL - 10K \cdot \log_{10}(d_{12} / d_0) + G(\vartheta_{12}) + G(\vartheta_{21})$$

Modeled Radiation Pattern



Main lobe: +5 dBi

Back lobe: −15 dBi

Directional gain trades 360° coverage for extended range and interference rejection.

Proposed Mechanism: Scanning Packets

1

Broadcast Scanning Packet

Unsynchronized nodes broadcast a new "Scanning Packet" while their radio stays open, listening across frequencies.

2

Extract Neighbor Info

Receiving nodes extract the sender's MAC ID, current antenna angle, and RSSI to build a virtual neighbor list (Algorithm 1).

3

Synchronize via EB

Once a node receives an Enhanced Beacon (EB) and synchronizes, it stops sending scanning packets and starts sending EB itself.

4

Directed Transmission

Future broadcasts on shared cells target a known neighbor's direction (Algorithm 2) instead of a random direction — raising success rate.

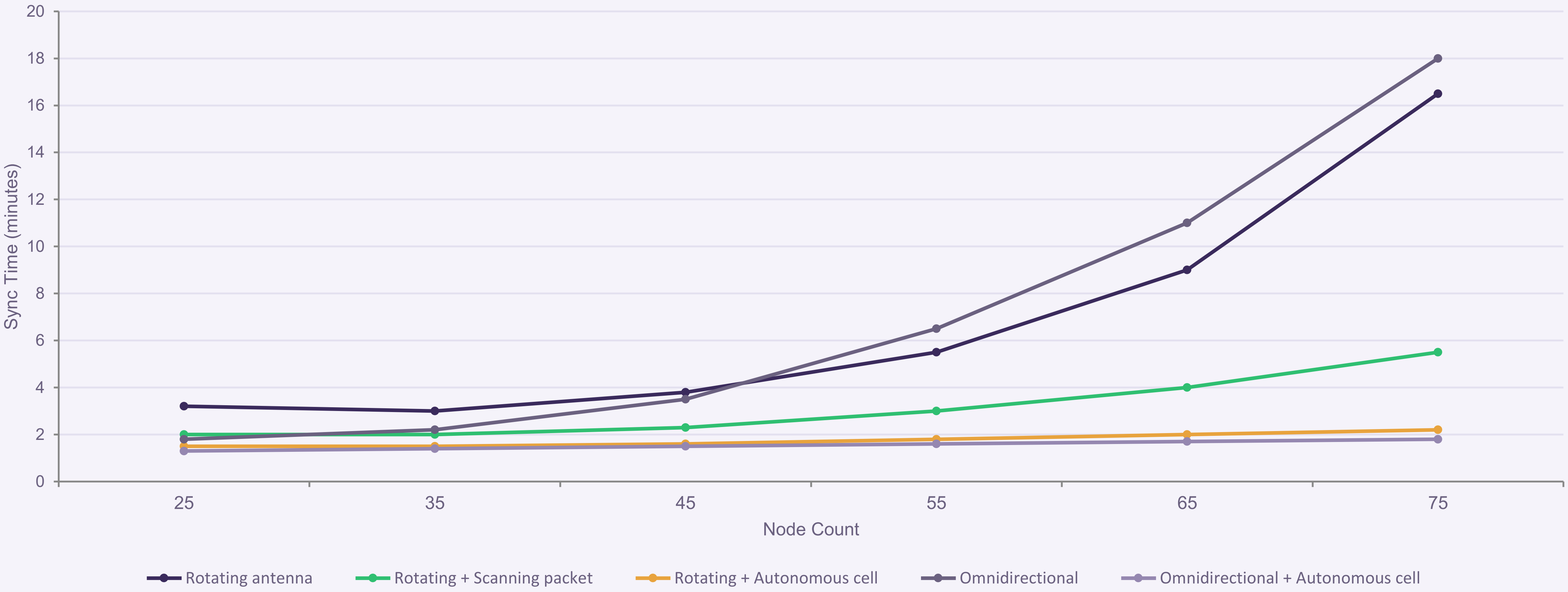
New nodes can still be discovered: when transmitting or listening, a random direction is chosen with probability P = 1 / (neighbor count + 1).

Experimental Setup

Simulator	Cooja, on Contiki OS — 10 repetitions, averaged
Frame Length	101 slots
Shared Cells	1
EB Send Interval	16 s (min) – 50 s (max)
Range (Omnidirectional)	50 m
Range (Smart Antenna)	15 – 80 m
Scenario Area	200 m × 200 m
Node Count Tested	25, 35, 45, 55, 65, 75

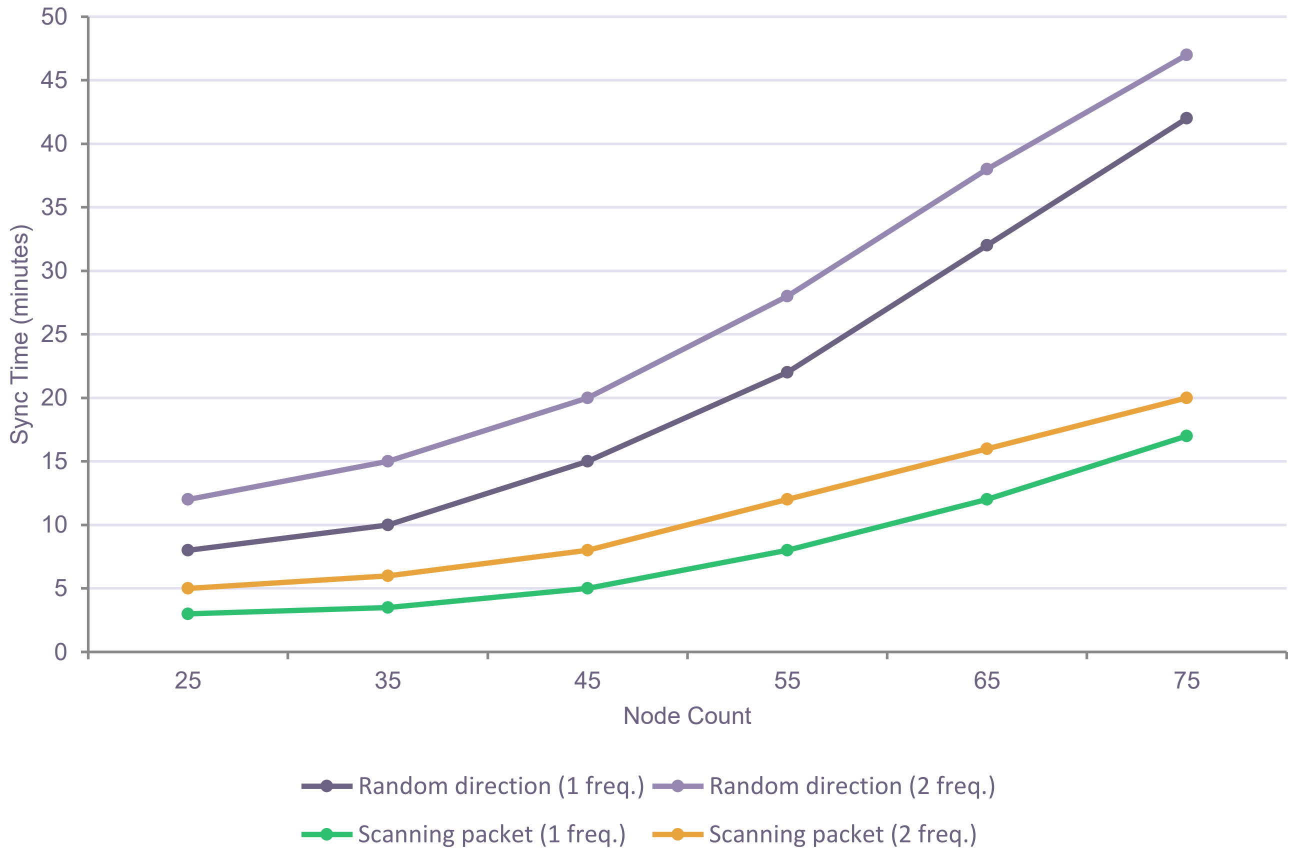
Test runs until the network is fully synchronized. Nodes are placed randomly within the scenario area.

Results: Sync Time by Antenna Configuration



Autonomous-cell solutions scale best as density increases; scanning packets help rotating antennas the most in dense scenarios.

Results: Effect of Scanning Packets



~25%

Faster network synchronization using scanning packets vs. random-direction transmission.

More frequency channels increase total sync time (each must be scanned in turn) — but scanning packets consistently outperform random-direction transmission at every channel count.

Discussion

1 Omnidirectional Struggles at Scale

Performs well in small scenarios, but degrades sharply as density rises due to more frequent interference and collisions.

2 Rotating Antennas Excel in Dense Networks

Narrow beams reduce collisions as density increases — but need more neighbors in range before showing this benefit.

3 Autonomous Cells Are the Biggest Win

Duplicating control messages per neighbor and sending over dedicated, autonomously assigned cells keeps sync time short and scalable, regardless of density.

4 Scanning Packets Complement Autonomous Cells

By directing shared-cell transmissions toward known neighbors instead of random directions, sync time improves by up to 25%.

Conclusion

- A new Scanning Packet lets unsynchronized nodes with directional antennas discover neighbors faster in 6TiSCH networks.
- Directing shared-cell transmissions toward known neighbors — rather than random directions — improves synchronization time by ~25%.
- Autonomously assigned cells per neighbor provide the largest, most scalable improvement across all tested node densities.
- Future work: apply machine-learning approaches to further optimize shared-cell utilization in directional 6TiSCH networks.

~25%

Faster network synchronization

25–75 nodes
tested densities

New Scanning Packet mechanism

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