# An Efficient Centralized Scheduling Algorithm in IEEE 802.15.4e TSCH networks

By

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# Overview

Introduction to IEEE 802.15.4e TSCH

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Conclusion and Future Work

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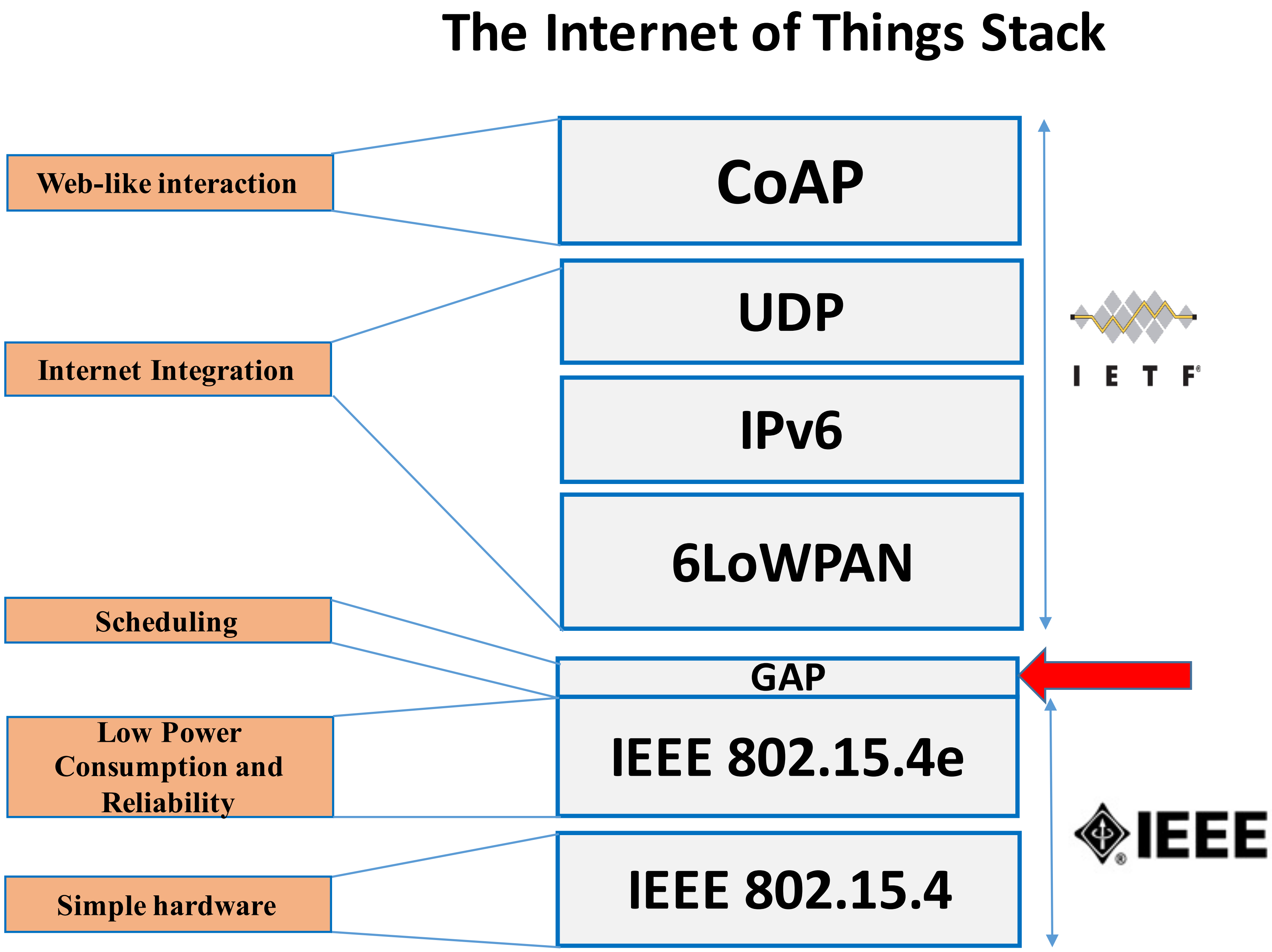
# Introduction to IEEE 802.15.4e TSCH



# Various Network Stacks

## WIA-PA

| |
|---|
| Object Oriented – Tunneling Support to Legacy Applications |
| |
| Star, Mesh and Star Mesh Topologies, Static Routing, Addressing, |
| IEEE 802.15.4e |
| IEEE 802.15.4 (2.4GHz) |

## ISA100.11a

| |
|---|
| ISA100.11a Objects: Legacy Protocols |
| UDP End to End Secure Session |
| 6LowPAN (RFC 4944) |
| IEEE 802.15.4e |
| IEEE 802.15.4 (2.4GHz) |

## WirelessHART

| |
|---|
| Commands: HART + Wireless |
| TCP-Like |
| Hart Addressing Local Routing |
| IEEE 802.15.4e |
| IEEE 802.15.4 (2.4GHz) |

## OpenWSN

| | | |
|---|---|---|
| PCE | CoAP | 6LowPAN ND |
| TCP | UDP | ICMP |
| IPv6 | RPL | |
| 6LoWPAN | | |
| 6TOP | | |
| IEEE 802.15.4e | | |
| IEEE 802.15.4 | | |

## Contiki OS

| | |
|---|---|
| CoAP/REST ENGINE | |
| 6LoWPAN | |
| IPv6 | ContikiRPL |
| 6LoWPAN | |
| CSMA | |
| RDC* | |
| IEEE 802.15.4 | |

## Riot OS

| | |
|---|---|
| CoAP | |
| UDP | |
| RPL | |
| IPv6 | ICMP |
| 6LoWPAN | |
| IEEE.802.15.4 -MAC | |
| IEEE 802.15.4 -PHY | |

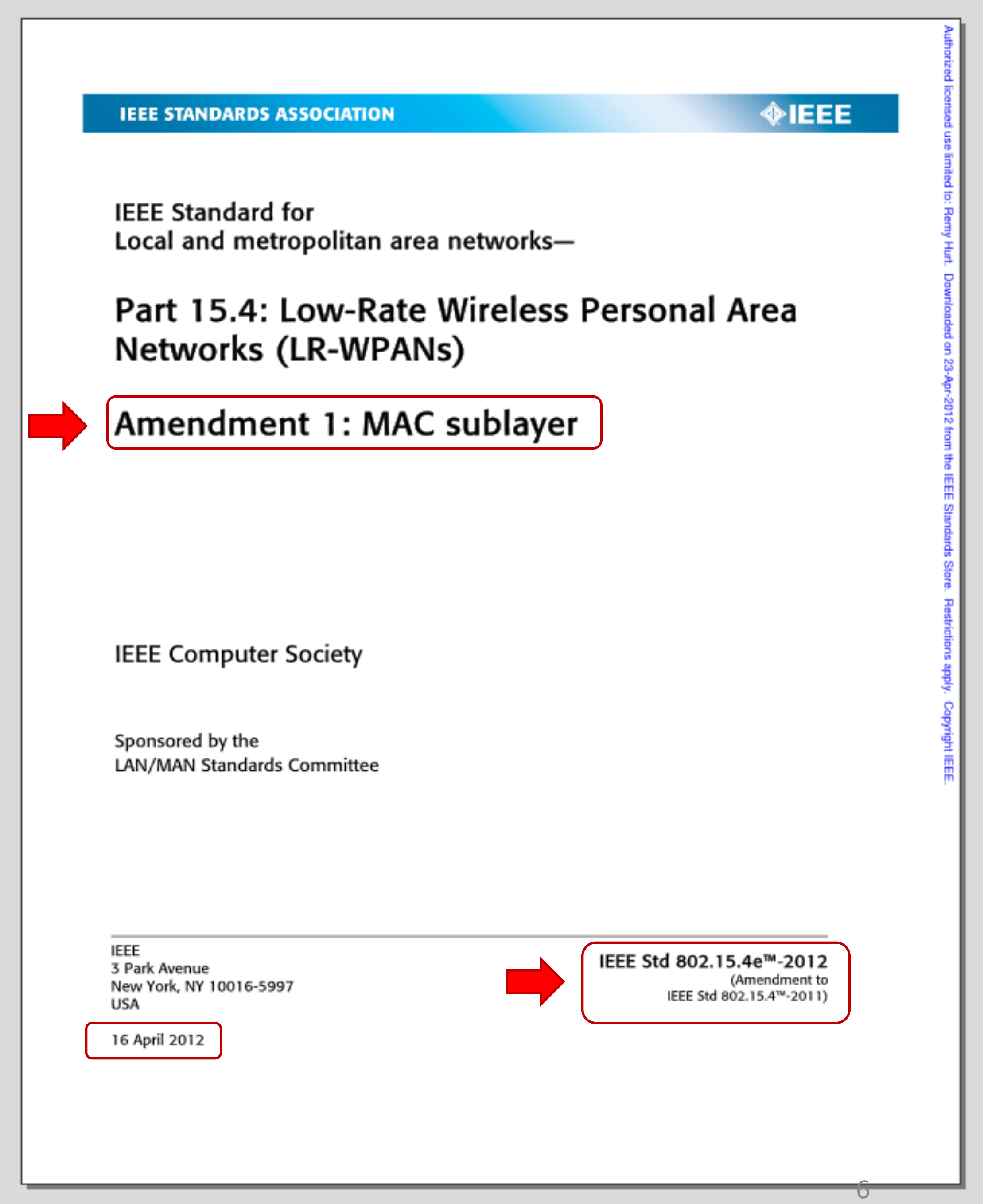
**STANDARDS**

- IEEE
- IETF
- ISA
- IEC

# IEEE802.15.4e TSCH

- Only amends MAC layer of IEEE 802.15.4-2011:
  - Does not modify the PHY layer

- Prime characteristics:
  - **TSCH: TimeSlotted (Synchronized),** to allow for ultra low power operation by synchronizing nodes.
  - **TSCH:Channel Hopping,** to give resilience to interference/multi-path fading



IEEE STANDARDS ASSOCIATION IEEE

IEEE Standard for
Local and metropolitan area networks—

**Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)**

**Amendment 1: MAC sublayer**

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

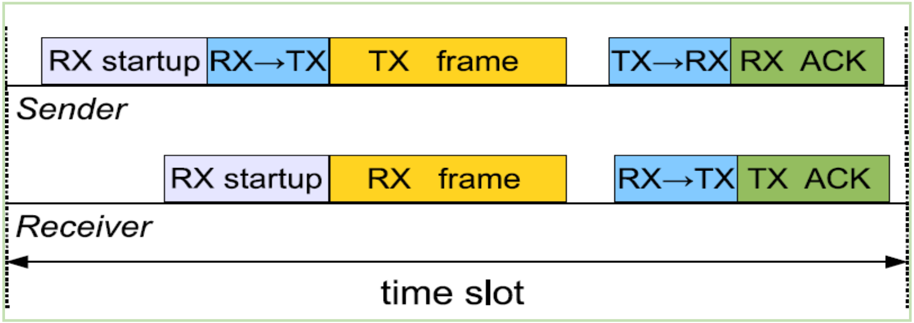
IEEE
3 Park Avenue
New York, NY 10016-5997
USA

16 April 2012

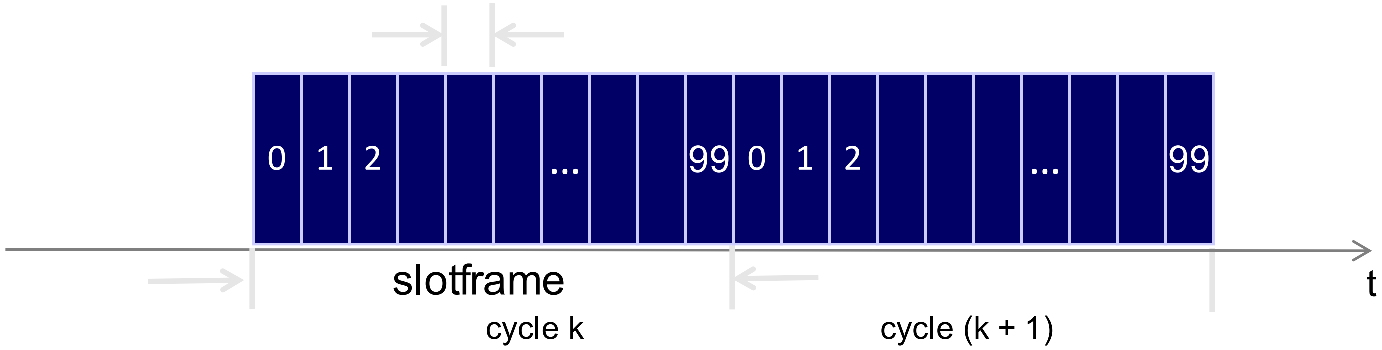
IEEE Std 802.15.4e™-2012
(Amendment to
IEEE Std 802.15.4™-2011)

# IEEE802.15.4e TimeSlotted CH

- **TSCH: TimeSlotted (Synchronized)**
  - Time is divided in time slots
  - All motes are *synchronized* to a given slotframe
  - *Slotframe:* group of time slots which repeats over time
  - Number of time slots per slotframe is tunable




A single slot is long enough for the transmitter to send a maximum length packet and for the receiver to send back an ACK



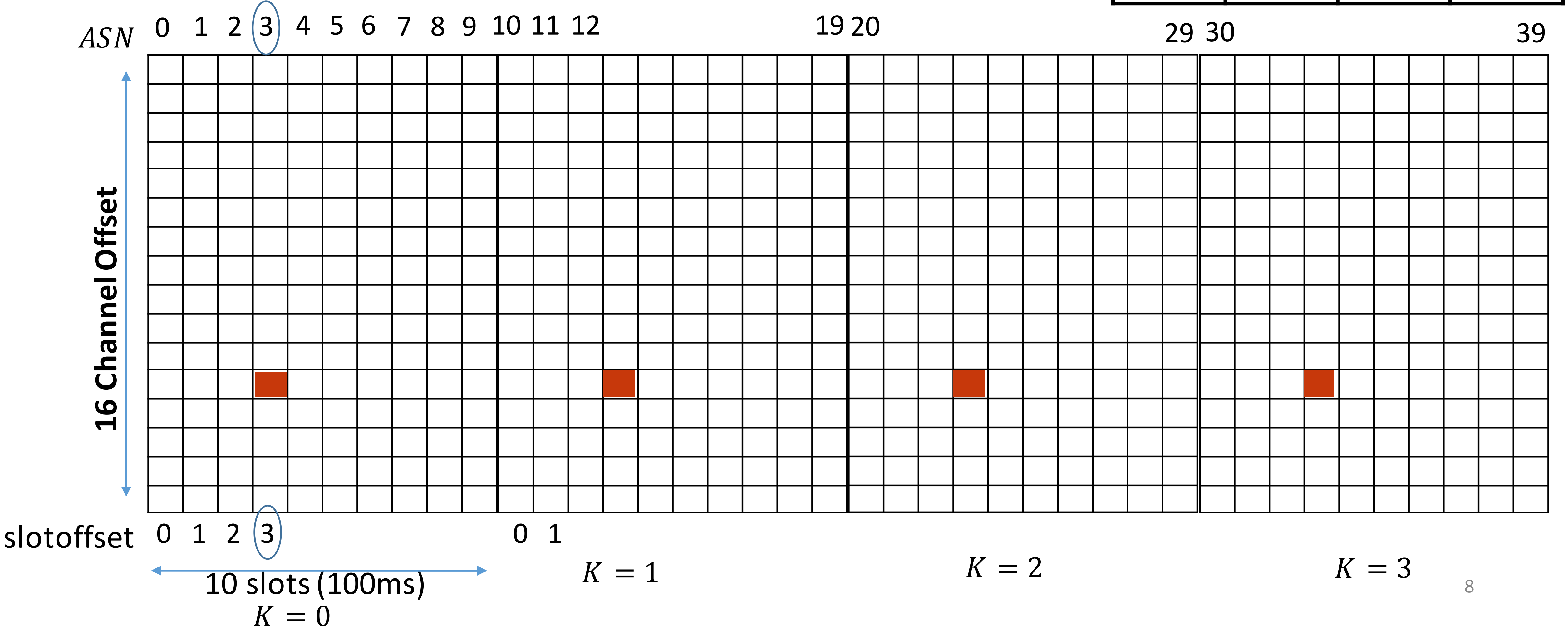
# IEEE 802.15.4e TS Channel Hopping

- Subsequent packets are sent at a different frequency
  - following a pseudo-random hopping pattern
- If a transmission fails, retransmission will happen on a different frequency

$$Actual\ Channel = (ASN + ChannelOffset)\ mod\ Numberof Channels$$

Frequency Translation

| k | ASN | ChOf | f |
|---|---|---|---|
| 0 | 3 | 4 | 7 |
| 1 | 13 | 4 | 1 |
| 2 | 23 | 4 | 11 |
| 3 | 33 | 4 | 5 |



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# Motivation

- Why Scheduling
  - The key to make wireless deterministic
- Problem:
  - IEEE 802.15.4e TSCH does not specify how a schedule is built
- Aim
  - To develop an efficient centralized scheduling algorithm in IEEE 802.15.4e TSCH networks.
- Approach: Graph Theory
- Goal:
  - To achieve a high throughput
  - To achieve a low packet loss rate

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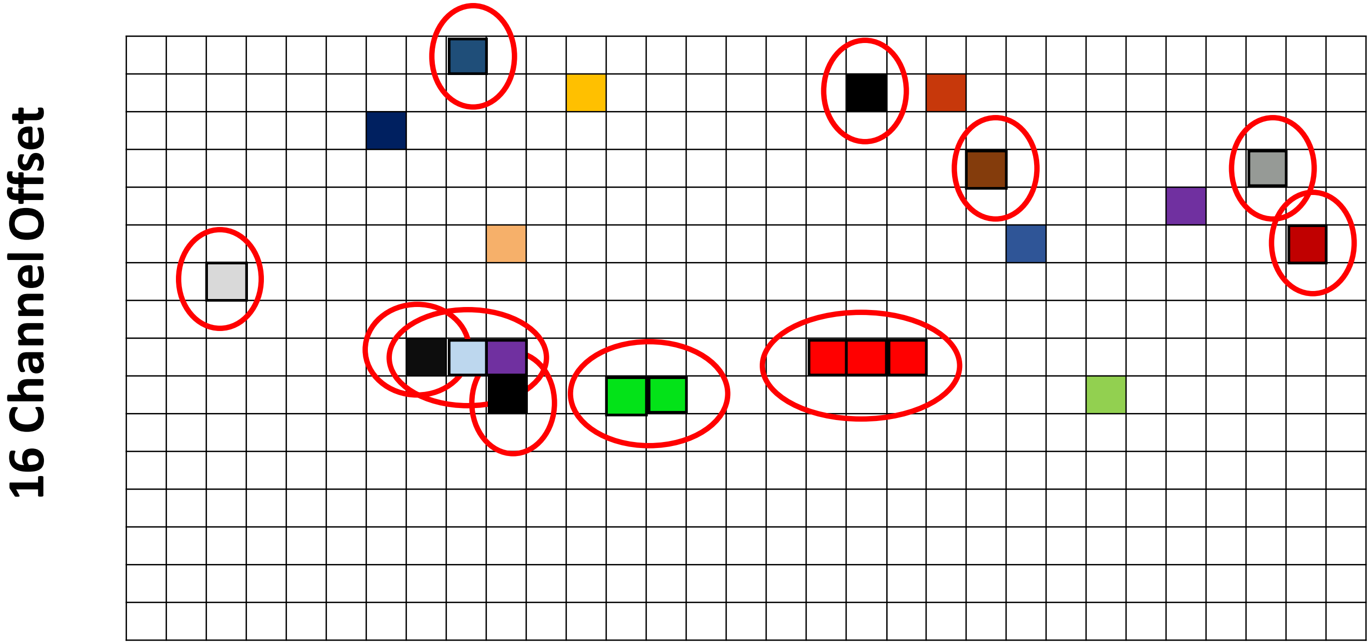
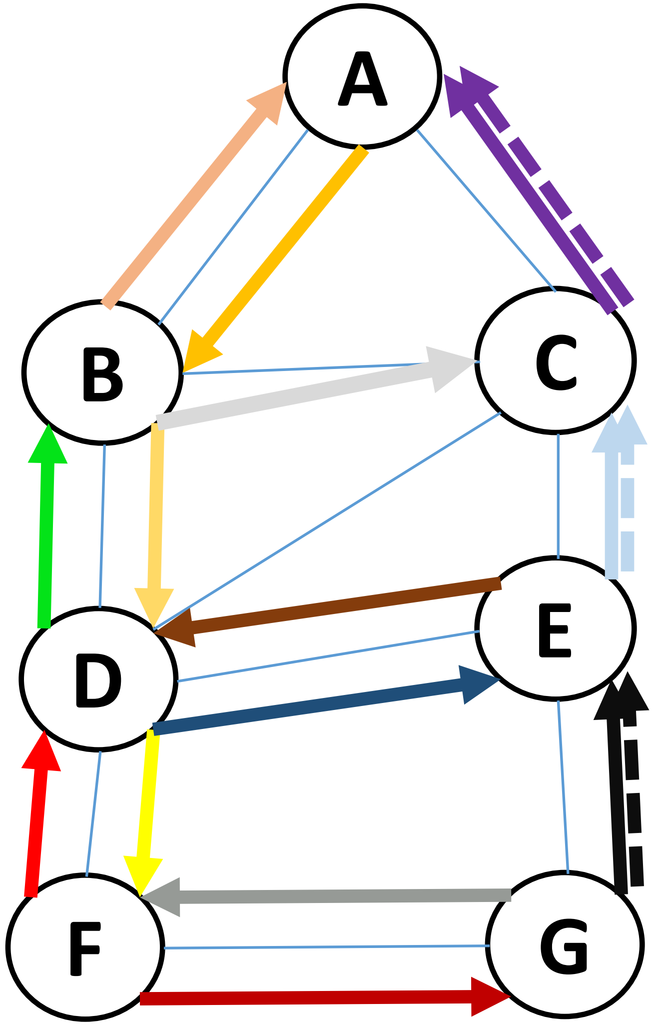
# IEEE 802.15.4e TSCH Schedule

- Cells are assigned according application requirements
- Metrics
  - ✓Packets/second
  - ✓Latency (G-E-C-A)
  - ✓Robustness (F-D-B-A)
    (F-D-E-C-A)
    (F-G-E-C-A)

… and energy consumption



# IEEE 802.15.4e TSCH Schedule

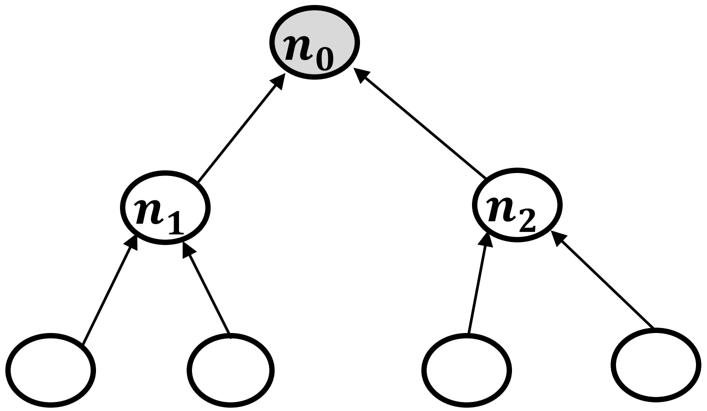
- **A schedule is built according to the specific requirements of the application**
- **Centralized Scheduling**
  - A manager node is responsible for building and maintaining the network schedule
  - Efficient for static networks
- **Distributed Scheduling**
  - No central entity
  - Each node decides autonomously
  - Scalable with large network size

IEEE 802.15.4e **does not** specify how a schedule is built!!!

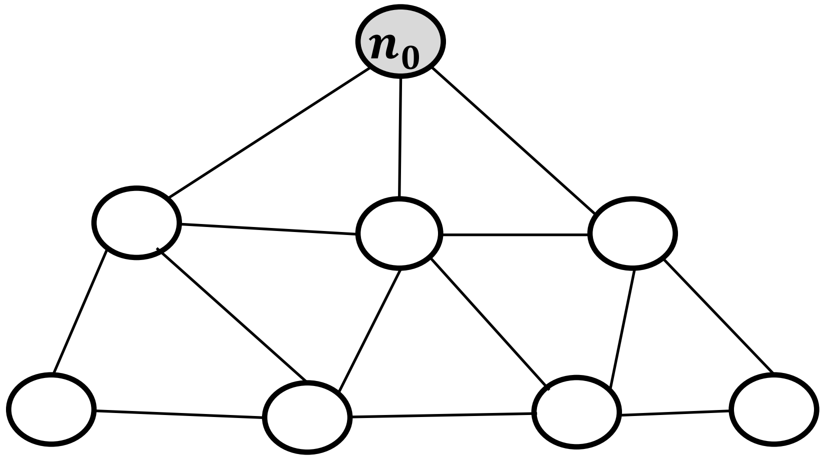
# Network Model

- ***We consider a centralized Approach***
- ***Topology Uncertainty***
- ***One gateway with many users***
- ***Modeled as a Network Graph G=(V,E)***

| Parameters | Notation |
|---|---|
| Distance between two nodes | $d_{ij}$ |
| Total number of nodes | $N$ |
| Set of nodes | $V = \{n_0, n_1, \cdots, n_N\}; \quad 1 \leq k \leq N-1$ |
| k-th node in the network | $n_k$ |
| Gateway | $n_0$ |
| Communication Range | $R_i$ |
| Number of packets transmitted | $U$ |
| Number of packets in the buffer | $Q$ |
| Frequency | $f$ |
| Timeslot | $t$ |
| Channel Capacity | $C_{k,f,t}$ |
| Link between two nodes | $l_{k,f,t}$ |
| Effective Rate | $M_{k,f,t}$ |




***Tree Topology***




***Mesh Topology***

# Problem Formulation

*A. Throughput Maximization Problem*

$$\max \sum_{k=1}^{N} \sum_{f=1}^{F} \sum_{t=1}^{T} X_{k,f,t} M_{k,f,t} \qquad (1)$$

***s.t***

$$\sum_{f=1}^{F} \sum_{t=1}^{T} X_{k,f,t} \geq 1;\ \forall k \in \{1, \ldots, N\} \qquad (2)$$

$$\sum_{k=1}^{N} X_{k,f,t} \leq 1;\ \forall f \in F;\ \forall t \in T \qquad (3)$$

$$X_{k,f,t} \in \{0,1\};\ \forall k \in N;\ \forall f \in F;\ \forall t \in T \qquad (4)$$

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# Throughput Maximizing Scheduler

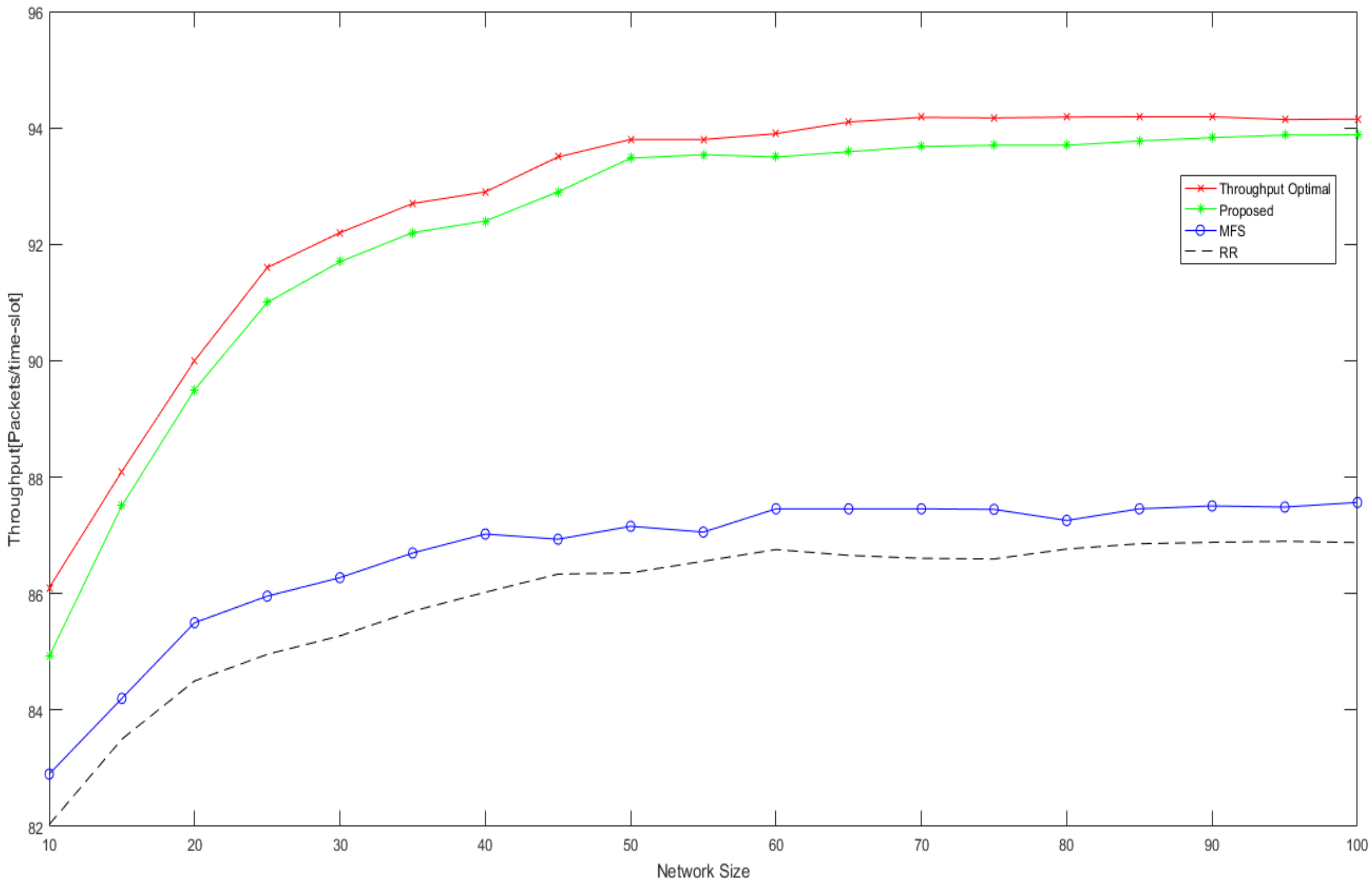
1. Trimming

$$\max \sum_{k=1}^{N} \sum_{f=1}^{F} Y_{k,f} M_{k,f} \quad \forall k \in N;\ \forall f \in F \qquad (5)$$

2. Weight Characterization
   - The Problem is equivalent to a Maximum Weighted Bipartite Matching Problem
   - $Construct\ a\ Bipartite\ Graph\ \ G = (U, V, E)$
   - Ensure perfect matching

3. Matching
   - We use Hungarian Algorithm
   - Low Computational complexity

# Average Network Throughput



# Conclusions and Future Work

- Summary
  - Graph theoretical approach is used to solve the throughput-maximizing scheduling problem in IEEE 802.15.4e TSCH Networks
  - The problem was formulated as a combinatorial optimization problem and NP-hard
  - We proposed a bipartite matching approach to solve the problem optimally in polynomial time
  - we solve the matching problem by Hungarian algorithm;
  - Our proposed scheduler guarantees high throughput under any admissible traffic.
- Future Work
  - Compare our results with other heuristic approaches such as Ant Colony Optimization, Genetic Algorithms
  - Use SDN approach to solve for scheduling
  - Use predictive mechanism for scheduling

Thank you for your attention

# Throughput Maximizing Scheduler

## PROCEDURE

### *(1) Trimming*

$$Let\ Y_{k,f} = \sum_{t=1}^{T} X_{k,f,t} \quad \forall k \in N;\ \forall f \in F \qquad (5)$$

**The objective formulation of the throughput maximization problem shown in equation 1 is reduced to equation 6**

$$\max \sum_{k=1}^{N} \sum_{f=1}^{F} Y_{k,f} M_{k,f} \quad \forall k \in N;\ \forall f \in F \qquad (6)$$

***s.t***

$$\sum_{f=1}^{F} Y_{k,f} \geq 1;\ \forall k \in N \qquad (7)$$

$$\sum_{k=1}^{N} Y_{k,f} \leq T;\ \forall f \in F \qquad (8)$$

$$Y_{k,f} \in \mathbb{N} \qquad (9)$$

***PROOF***

$\Pi = maximization\ problem,$

$\Pi' = \text{simplest equivalent maximization problem}$

$O_{\Pi'}(Y) = O_{\Pi}(X)$

Holds for an optimum solution $X^*$

This makes both problem to have the same solution