Temporary Resource Allocation for Event-driven Traffic in IEEE 802.15.4 DSME

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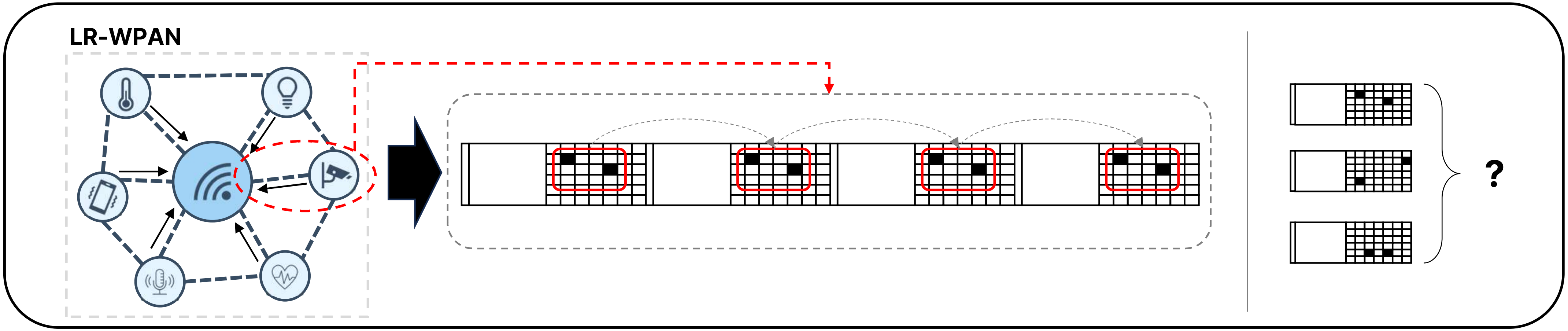
Contents

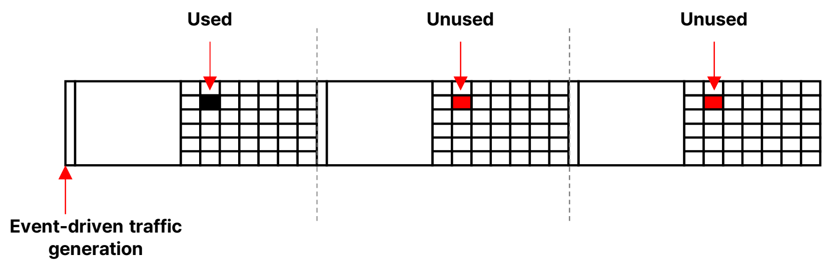
Introduction

- **IEEE 802.15.4 Deterministic and synchronous multichannel extension (DSME)**
  - Medium access control (MAC) protocol defined in IEEE 802.15.4-2015
- **Key features of DSME**
  - Assigns each data transmission to a guaranteed time slot (i.e., GTS) within repeating multi-superframes
  - Continuously allocates the same time slot index without negotiation
    - ✓ Efficient for managing periodic traffic
- **Issues with DSME**
  - No definition for channel and slot index selection
    - ✓ Many schemes have been proposed for the allocation of GTS



Introduction

- **Related works**

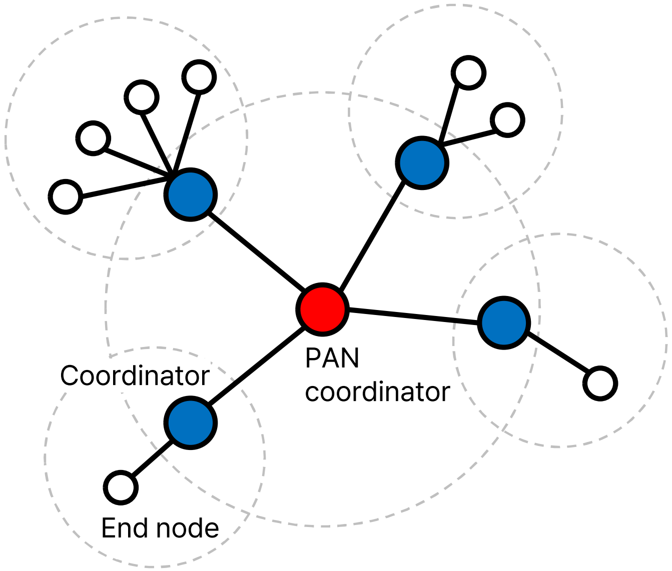
<table>
<tr><th>Title</th><th>Common Limitation</th></tr>
<tr><td>N. Choudhury, R. Matam, M. Mukherjee and J. Lloret, "A Beacon and GTS Scheduling Scheme for IEEE 802.15.4 DSME Networks," IEEE Internet of Things Journal, vol. 9, no. 7, pp. 5162-5172, Apr. 2022</td><td rowspan="4">Limited support for mixed periodic/event-driven traffic

</td></tr>
<tr><td>N. Choudhury and M. M. Nasralla, "A Proposed Resource-Aware Time-Constrained Scheduling Mechanism for DSME based IoV Networks," 2021 IEEE 94th Vehicular Technology Conference (VTC2021-Fall), Norman, OK, USA, 2021</td></tr>
<tr><td>H. Kurunathan, R. Severino, A. Koubaa and E. Tovar, "DynaMO—Dynamic Multisuperframe Tuning for Adaptive IEEE 802.15.4e DSME Networks," IEEE Access, vol. 7, pp. 122522-122535, 2019</td></tr>
<tr><td>S. -W. Lee, J. -H. Kwon, X. Zhang and E. -J. Kim, "Traffic-Adaptive CFP Extension for IEEE 802.15.4 DSME MAC in Industrial Wireless Sensor Networks," IEEE Access, vol. 9, pp. 94454-94469, 2021</td></tr>
</table>

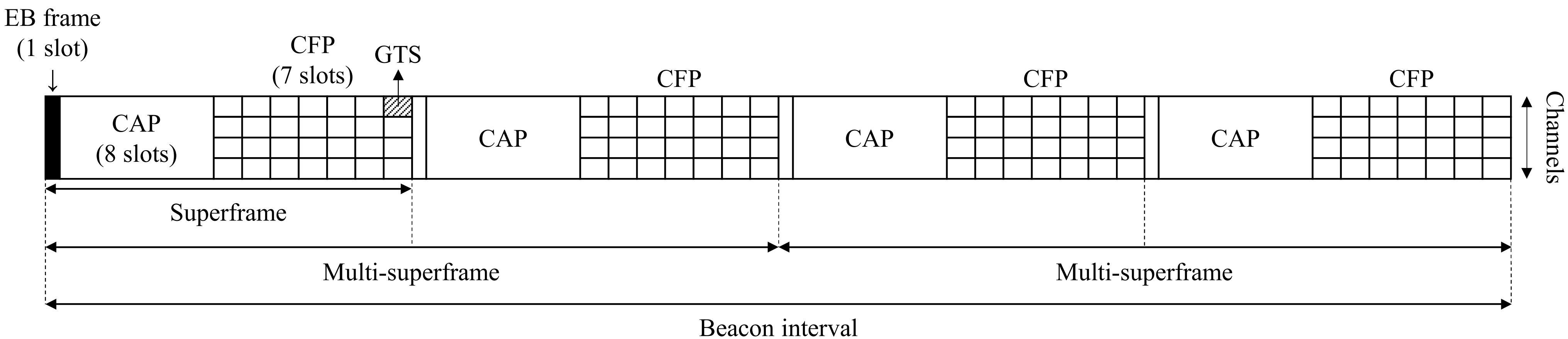
- **Proposed scheme: Temporary Resource allocation (TRA)**
  - Key features
    - ✓ Determines the GTS allocation process based on traffic type
      - Periodic traffic → Legacy GTS allocation/deallocation
      - Event-driven traffic → Temporary resource allocation

Address static and inefficient GTS management in legacy DSME and existing studies.

IEEE 802.15.4 DSME overview

- **IEEE 802.15.4 DSME network**
  - Consists of Personal area network (PAN) coordinator, Coordinators, End nodes
  - Nodes operate based on the multi-superframe structure
- **Multi-superframe**
  - Repeated in a cyclic manner
  - Consists of multiple superframes
- **Superframe**
  - EB frame : Period during which the coordinator transmits the enhanced beacon (EB)
  - Contention access period (CAP): Period for exchanging control packets using CSMA/CA
  - Contention free period (CFP): Period for data transmission without contention using GTS



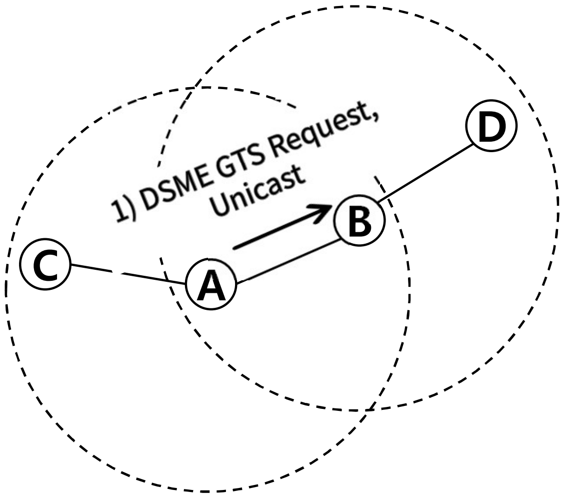


DSME multi-superframe structure

IEEE 802.15.4 DSME overview

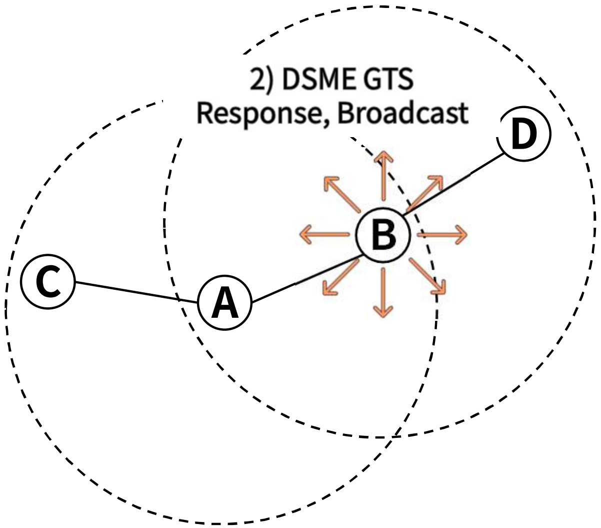
- **DSME GTS allocation & deallocation**

a) REQUEST, unicast
Payload: type (Allocation), direction, preferred superframe ID, preferred slot ID, number of DSME-GTSs, priority, DSME-GTS SAB sub block: {00001100101100...}
→ *time slot*



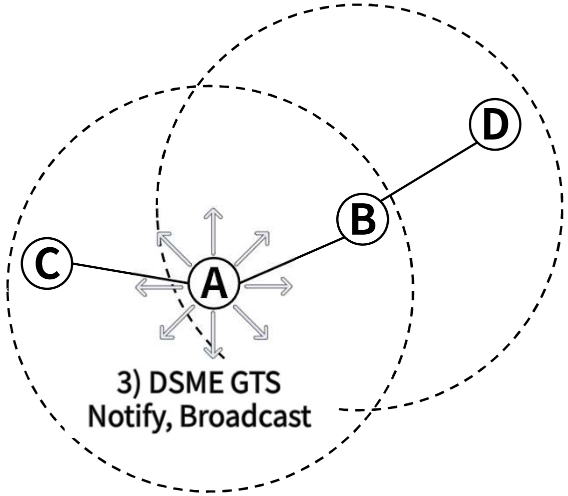
1) DSME GTS Request

b) RESPONSE, broadcast
Payload: type (Allocation), direction, destination Address (Node A), channel offset, newly allocated DSME-GTS SAB sub block: {00110000000000...}
→ *time slot*



2) DSME GTS Response

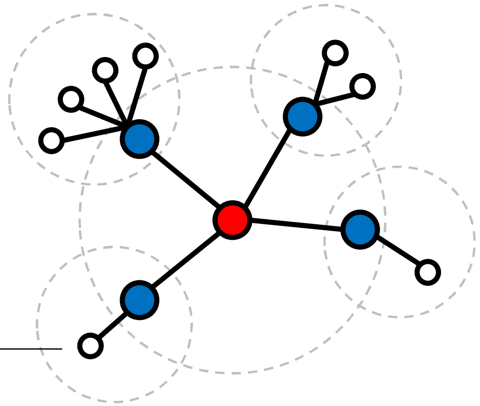
c) NOTIFY, broadcast
Payload: type (Allocation), direction, destination address (Node B), channel offset, newly allocated DSME-GTS SAB sub block {00110000000000...}
→ *time slot*

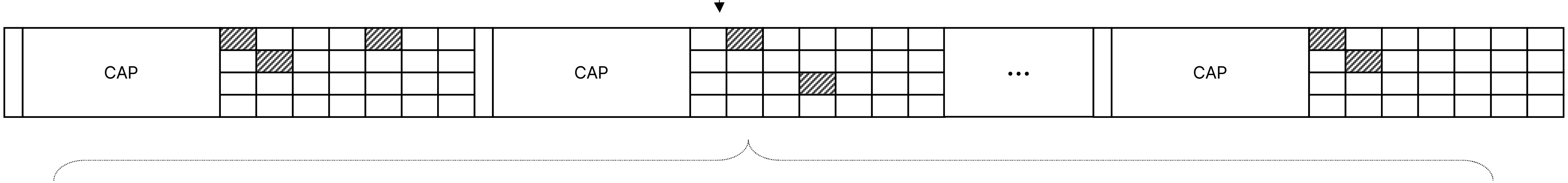


3) DSME GTS Notify

IEEE 802.15.4 DSME overview

- **GTS management structure**
  - **Slot allocation bitmap (SAB)**
    - Tracks which time slots are used (1) or free (0) for each superframe and its 1-hop neighbors
  - **Allocation counter table (ACT)**
    - Data for each allocated GTS → includes superframe ID, slot ID, channel, direction (Tx/Rx), address, idle counter





1100100	0101000	···	1100000

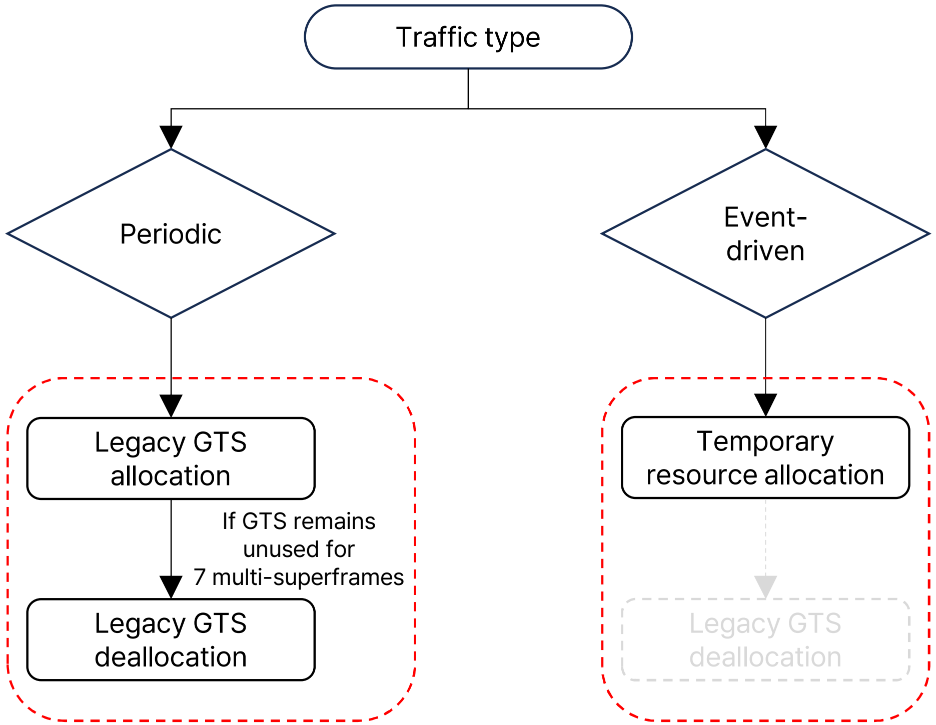
SAB

Superframe ID	Slot ID	Channel ID (Channel offset)	Direction	Source /Destination	···	Counter
0	8	1	RX	0x0000		2
0	9	1	TX	0xfffd		0
0	12	1	TX	3F9A7C		1
⋮	⋮	⋮	⋮	⋮	⋮	⋮

ACT

Temporary resource allocation (TRA)

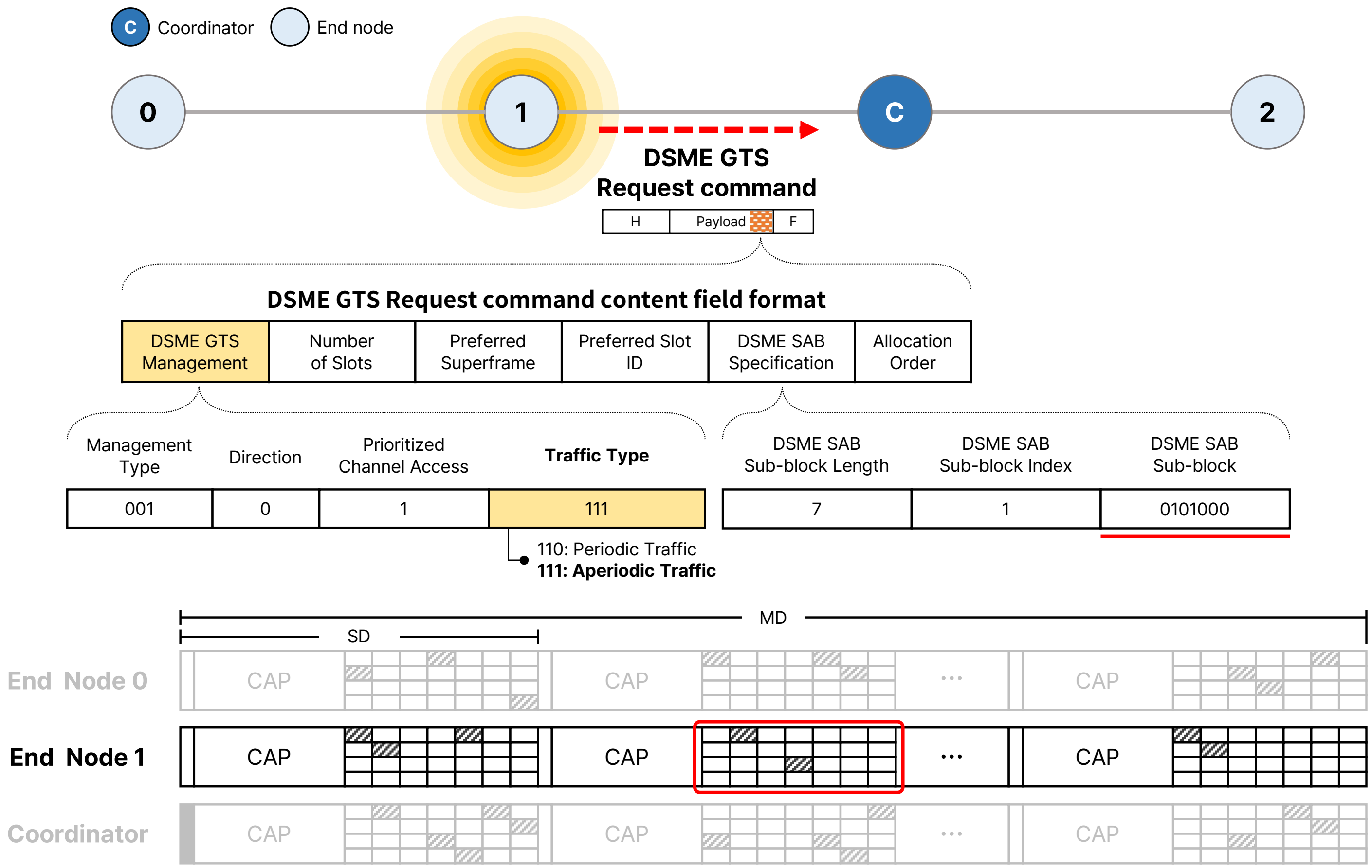
- **Traffic type check**
  - Determine whether traffic is periodic or event-driven
- **Periodic traffic**
  - Legacy GTS allocation
  - Deallocated if unused for 7 consecutive multi-superframes
- **Event-driven traffic**
  - Temporary GTS allocation
  - Automatically released in the next multi-superframe

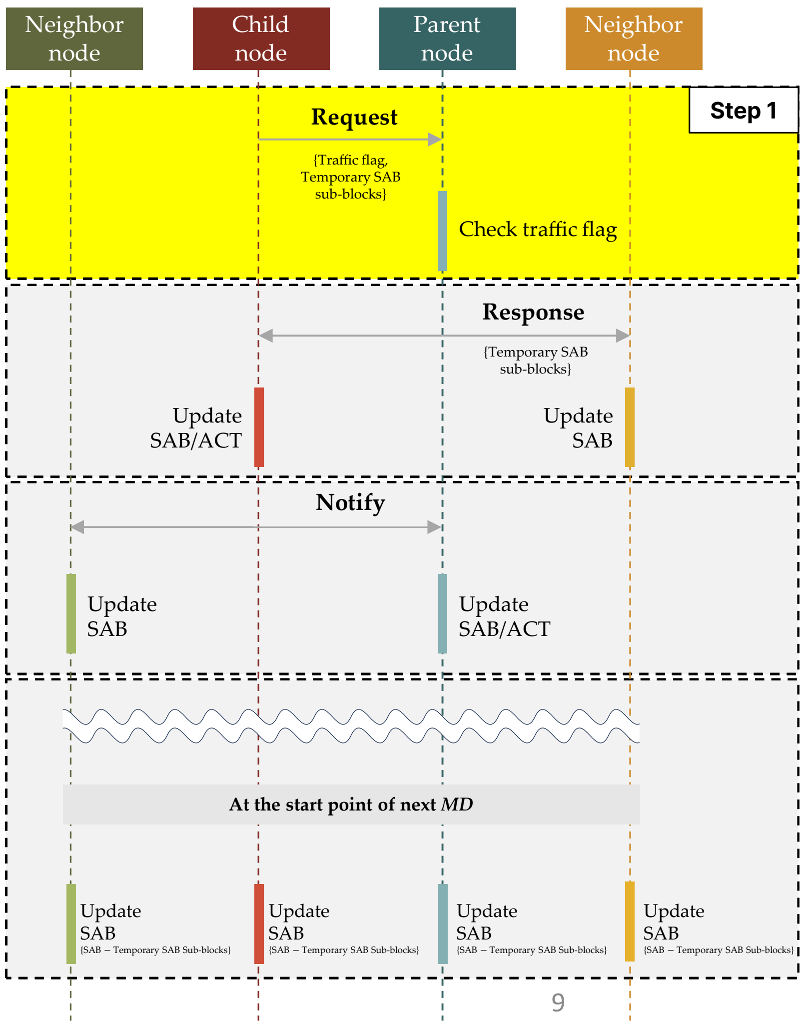


Enhance resource utilization by reducing the number of unused GTSs.

Temporary resource allocation (TRA)

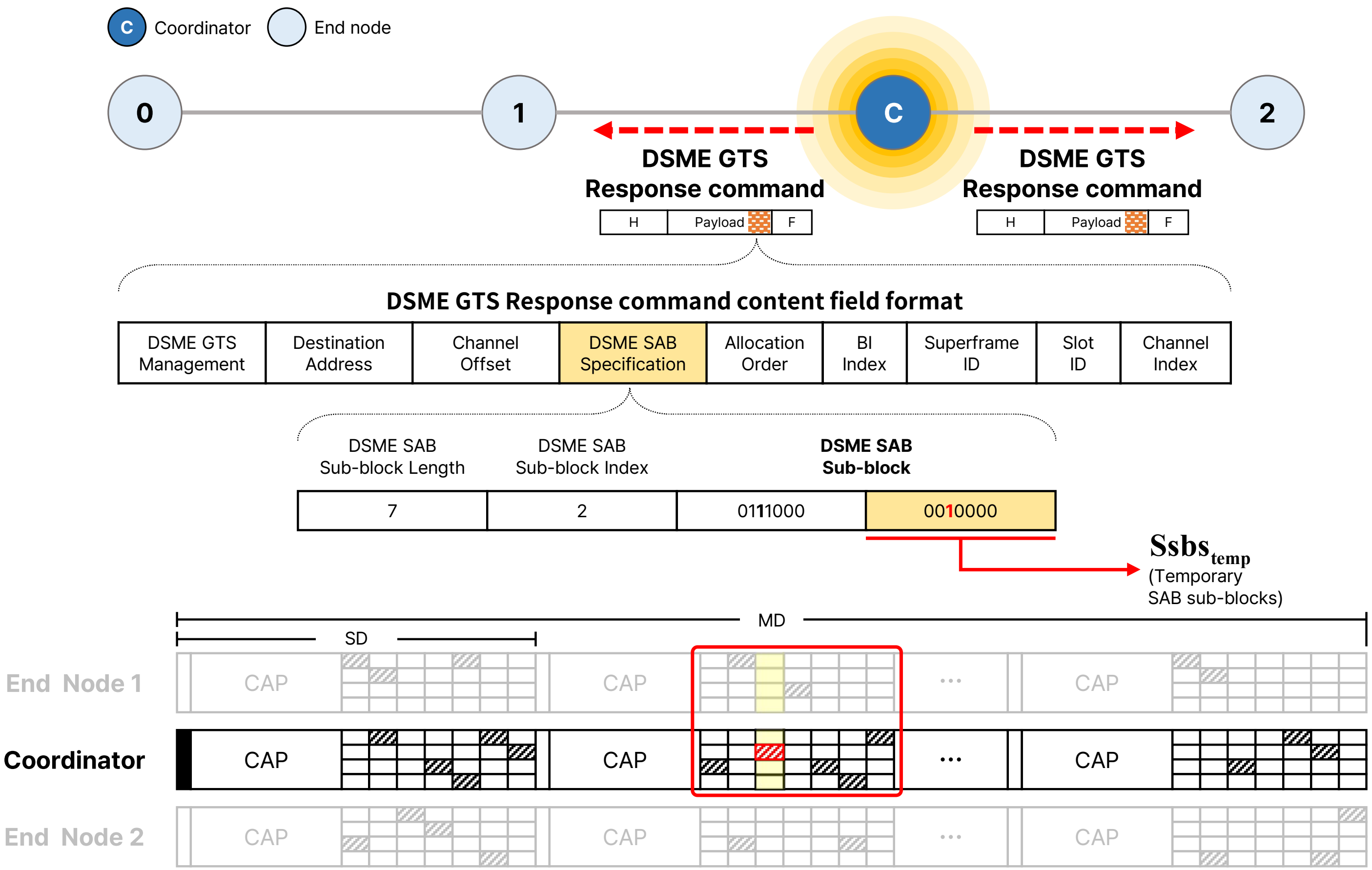
- **Step 1. DSME GTS Request**
  - End node sends a DSME GTS Request command to its parent node (Coordinator).

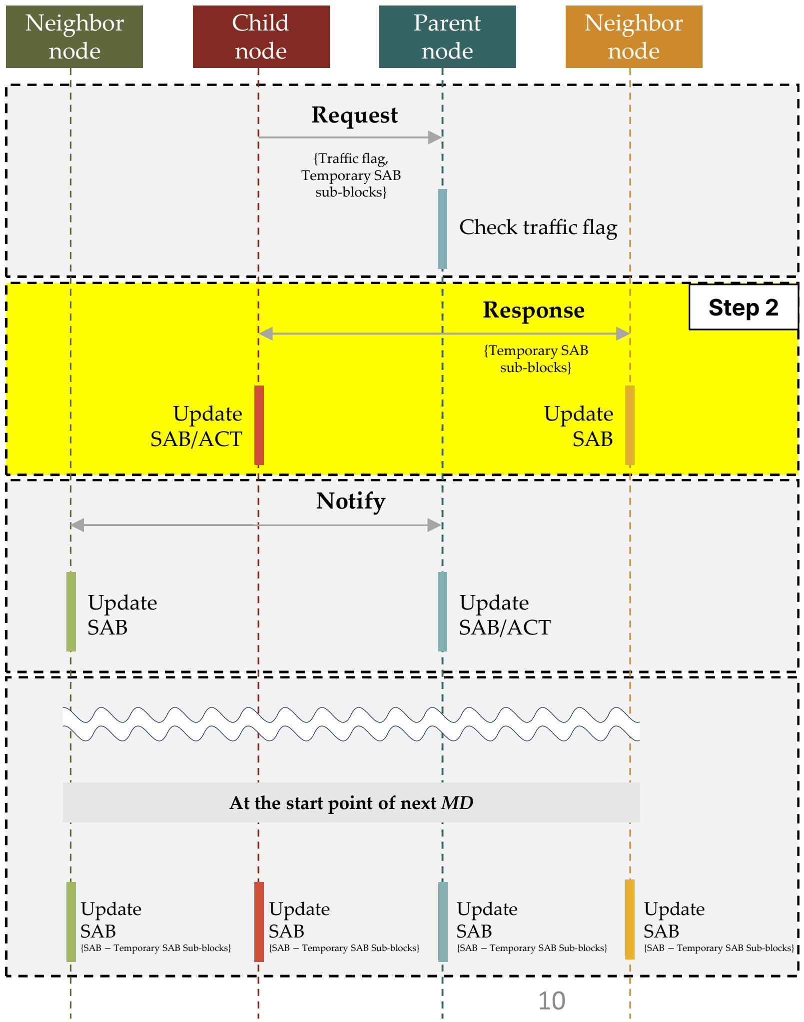




Temporary resource allocation (TRA)

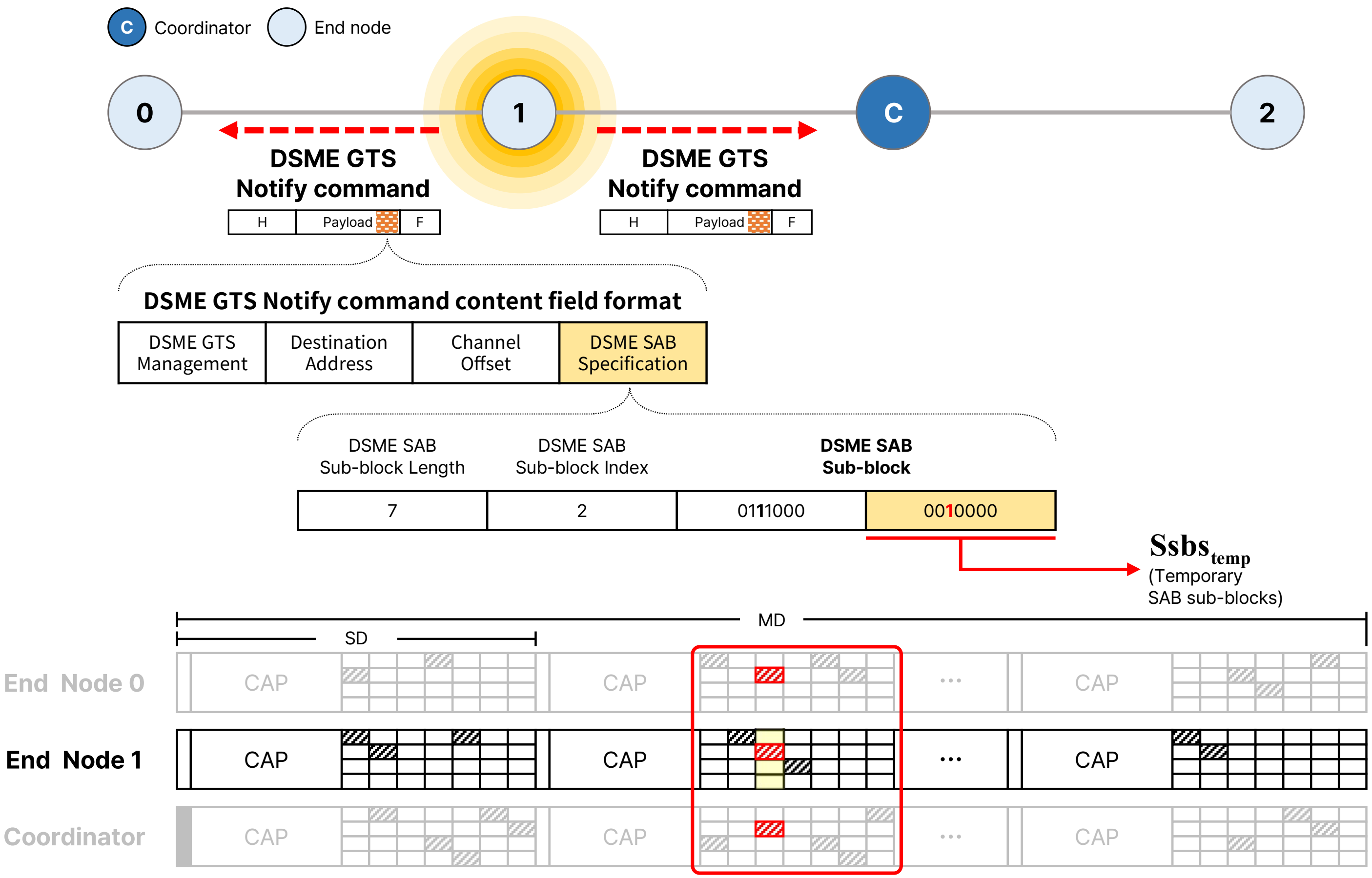
- **Step 2. DSME GTS Response**
  - The parent node (Coordinator) broadcasts the DSME GTS Response command to all neighboring nodes, including End node 1.

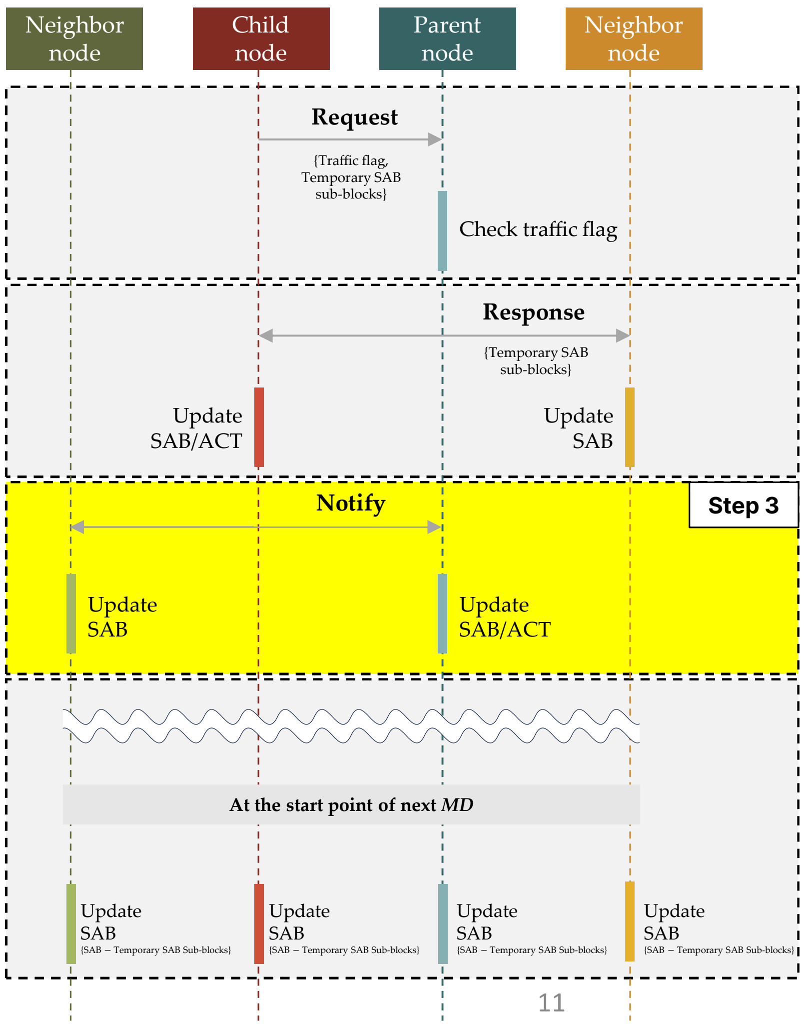




Temporary resource allocation (TRA)

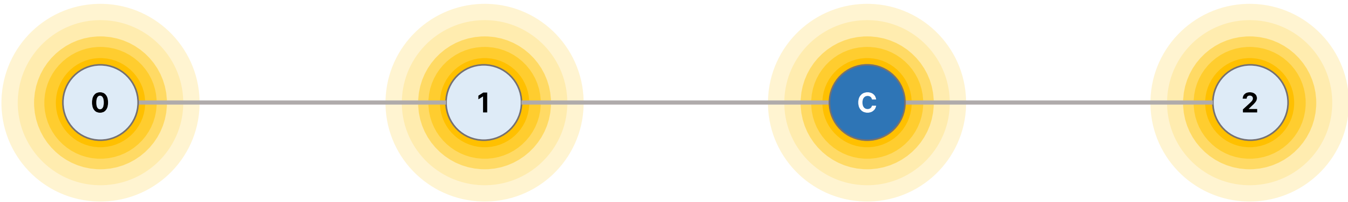
- **Step 3. DSME GTS Notify**
  - End node broadcasts a DSME GTS Notify command to its neighboring nodes, including the parent node (coordinator).

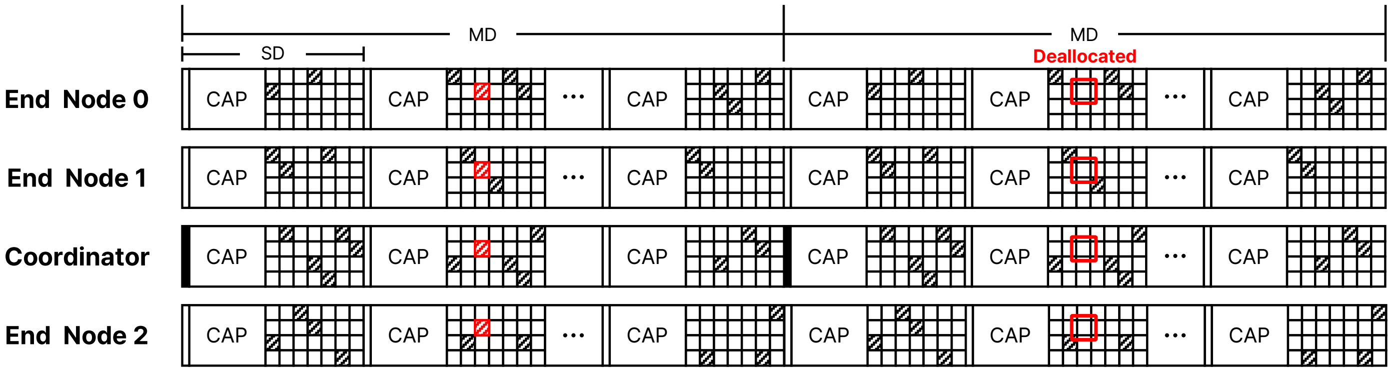


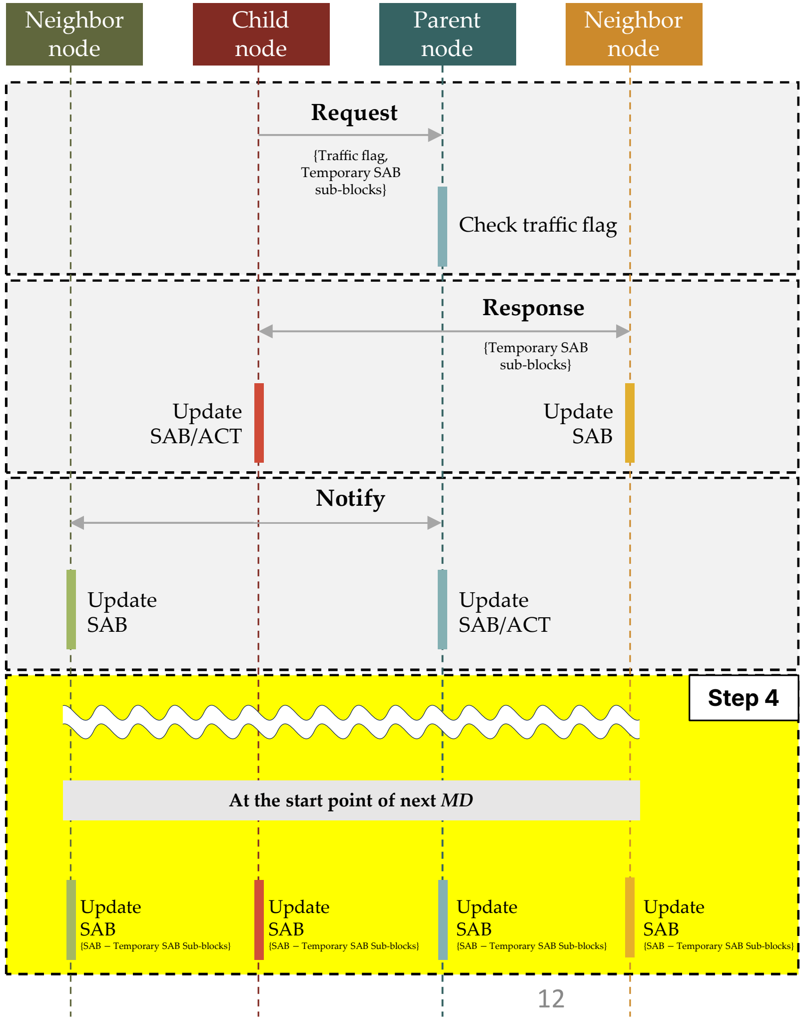


Temporary resource allocation (TRA)

- **Step 4. DSME GTS Deallocation**
  - Each node updates its own SAB independently.

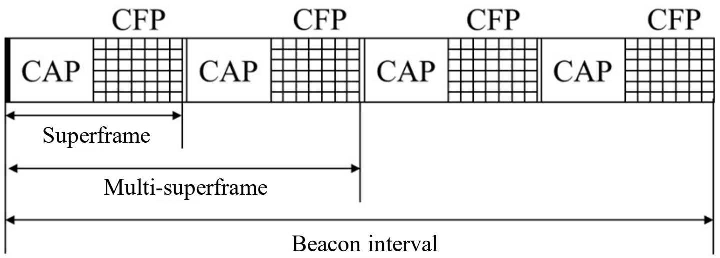




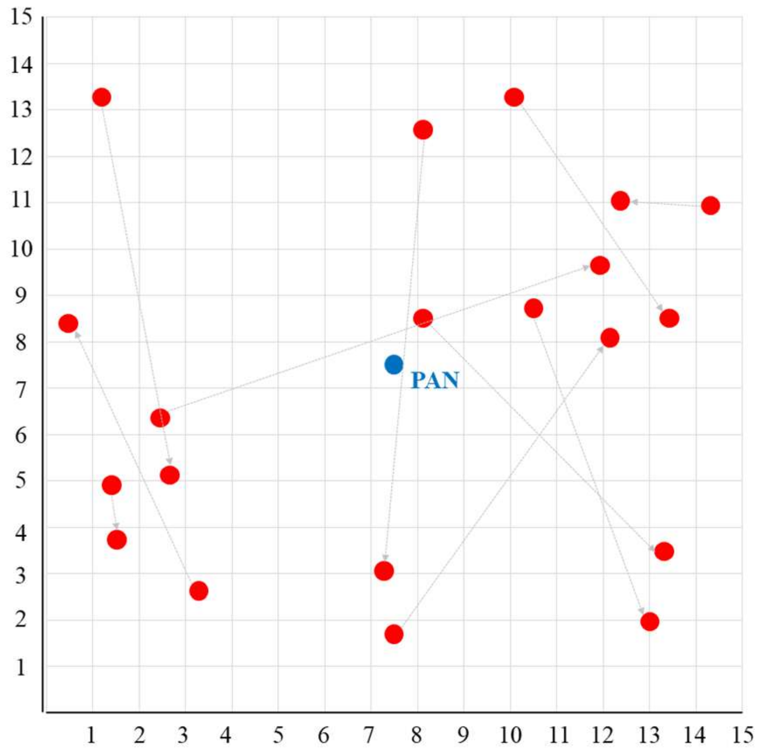


Performance evaluation

- **Simulation settings and configuration**
  - **Network configuration**
    - 1 PAN coordinator, 10-80 transmitter/receiver node pairs
      - ✓ Each node forms a transmission pair with a peer to exchange data
    - Nodes are randomly distributed within a 15 m × 15 m area
    - Communication range: 10 m
  - **Traffic pattern of transmitter nodes**
    - 60% of nodes generate periodic traffic
    - 40% generate event-driven traffic
      - ✓ Aperiodic traffic generation is controlled by probability: 20%, 40%, 60%, 80%
  - **Traffic settings**
    - Each transmitter node generates 1 packet per multi-superframe
    - Each node has a queue that can hold up to 10 packets



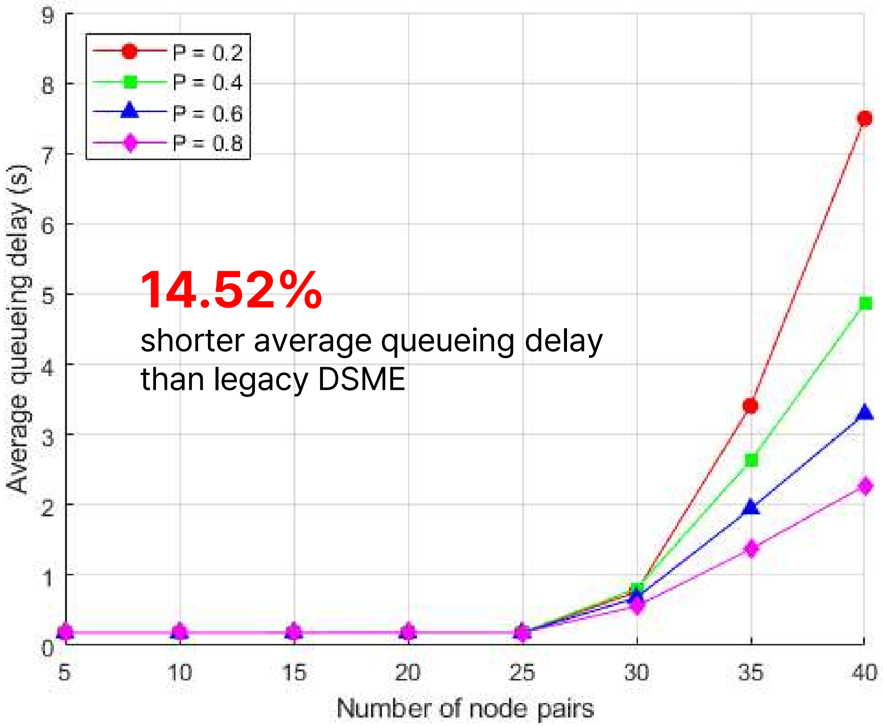
Multi-superframe structure in simulation



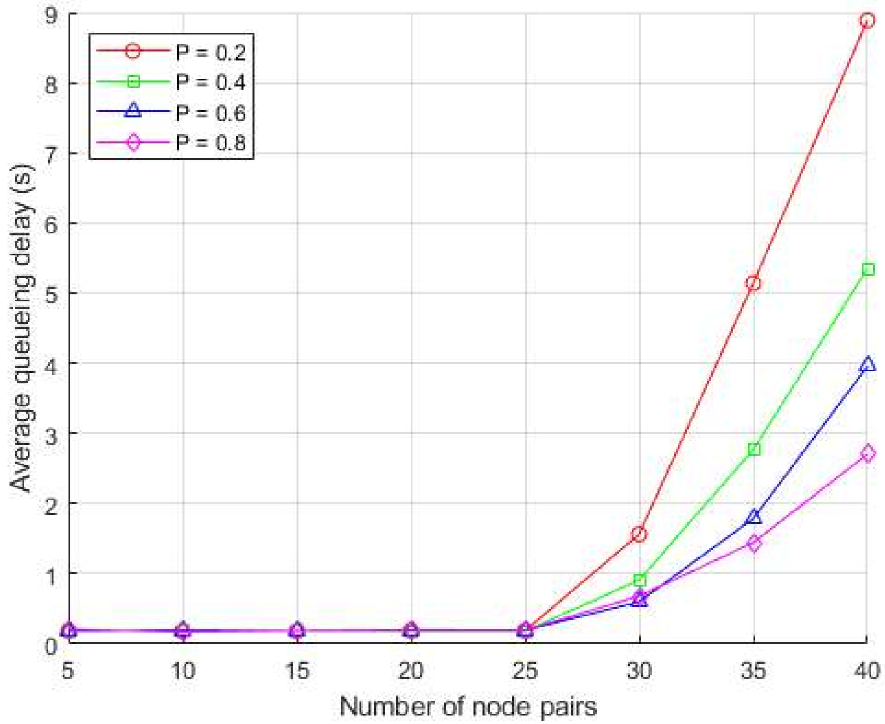
Example of network deployment with 20 nodes

Performance evaluation

- **Average queueing delay**
  - Average time each packet waits in the queue
  - Frequent GTS deallocations allow more nodes to obtain GTS allocation opportunities



TRA (Temporary resource allocation)



Legacy DSME

Conclusion

- **Proposed a Temporary resource allocation (TRA) scheme for IEEE 802.15.4 DSME**
  – To solve the problem of inflexible and inefficient GTS usage under event-driven traffic conditions
- **Limitations of existing studies**
  – Resource waste
  – Limited adaptability to dynamic or unpredictable traffic patterns
  – Degraded performance in hybrid (periodic + event-driven) traffic environments
- **Key features**
  – Determines the GTS allocation process based on traffic type
    ✓ Periodic traffic → Legacy GTS allocation/deallocation
    ✓ Event-driven traffic → Temporary resource allocation

Requirements	TRA Solution
Efficient GTS utilization	Automatically released if unused after 1 interval
Support for event-driven traffic	Temporary SAB-based allocation
Standards compatibility	Fully compliant with IEEE 802.15.4 DSME structure

Thank You