Schedule-based MACs: NAMA, LAMA, PAMA and TRAMA and DYNAMMA and a little of TRANSFORMA

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Outline

Protocol Features

Protocol Description
- NAMA, LAMA, PAMA
- TRaffic Adaptive Medium Access
- DYNamic Multi-channel Medium Access

Comparison

Protocol Performance
- NAMA, LAMA, and PAMA
- TRaffic Adaptive Medium Access
- DYNamic Multi-channel Medium Access

Overall Comparison
### Features of TRAMA, FLAMA and DYNAMMA

#### Common to all three
- Schedule based data transmission
- Energy-efficient
- Use of 2-hop neighborhood information

<table>
<thead>
<tr>
<th>TRAMA</th>
<th>FLAMA</th>
<th>DYNAMMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application independent</td>
<td>Designed for sensor-networks</td>
<td>Application independent</td>
</tr>
<tr>
<td>Explicit schedules</td>
<td>Flow-based</td>
<td>Flow-based</td>
</tr>
<tr>
<td>Single channel</td>
<td>Multi-channel ready</td>
<td>Multi-channel ready</td>
</tr>
<tr>
<td></td>
<td>Lightweight</td>
<td>Lightweight</td>
</tr>
</tbody>
</table>

Further Reading

Backup
- NAMA
- TRAMA

Description
- NAMA, LAMA, PAMA
- TRAMA
- DYNAMMA

Comparison
- NAMA, LAMA, and PAMA
- TRAMA
- DYNAMMA
The Need For 2-hop Neighborhoods

Hidden Terminals

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Hidden Terminals

TX 1

TX 2

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Backup
NAMA
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The Need For 2-hop Neighborhoods

Who Else Can Transmit?
The Need For 2-hop Neighborhoods

They Can

<table>
<thead>
<tr>
<th>TX</th>
<th>one of green nodes can transmit concurrently with red node</th>
<th>Sched-MAC</th>
</tr>
</thead>
</table>

Features

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- TRAMA
The Need For 2-hop Neighborhoods
How Could TX Know?

one of green nodes can transmit concurrently with red node
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NCR (Neighborhood Aware Contention Resolution)
The link between NAMA, LAMA, and PAMA

- NCR is about determining a priority allocation for each contending entity for each contention context that will be respected by all other contending entities.

**General NCR algorithm**

1. \( p_k^t = \text{Rand}(k \oplus t) \oplus k, \ k \in M_i \cup \{i\} \)
2. Exit if following is false: \( \forall j \in M_i, \ p_i^t > p_j^t \)
3. i may access the common channel during t
Performance of NCR in general
A queuing theory analysis

Delay in System

![Average Packet Delays in the System](image)

**Figure 1:** Average System Delay of Packets

Throughput in System

\[ S = \sum_k \min(\lambda_k, q_k) \]
Node Activation Multiple Access

Time Division Equations

- \( t' = t \mod T_p \)
- \( p' = (t / T_p) \mod P_s \)
- \( s' = [t / (T_p \times P_s)] \mod S_b \)

NAMA Algorithm

1. Compute the current part number \( p' \) using equations to the left
2. Exit if \( p' \neq p_i \)
3. Compute priority \( p'_i \) using NCR equation,
   \[ p'_k = \text{Rand}(k \oplus t) \oplus k, k \in M_i \cup \{i\} \]
4. Assign node \( i \) to time slot \( t_i = p'_i \mod T_p \)
5. Compute the current time slot \( t' \) in part \( p' \) using equations to the left
6. If \( t_i \neq t' \) then skip to step 10
7. Compute the set of contending neighbors
   \[ M_i = \{k | k \in N_i^1 \cup N_i^2 \text{ and } p_k = p' \text{ and } (p'_k \mod T_p) = t' \} \]
   where \( p'_k \) is obtained from the NCR equation and \( p_k \) is the part number chosen by node \( k \)
8. Exit if NCR equation 2, \( \forall j \in M_i, p'_i > p'_j \), does not hold for \( i \)
9. Access the common channel in current time slot \( t \) and exit
10. Exit if \( \exists k, k \in N_i^1 \cup N_i^2 \text{ and } p_k = p' \text{ and } (p'_k \mod T_p) = t' \)
11. The set of contending neighbors of node \( i \) now becomes:
    \[ M_i = \{k | k \in N_i^1 \cup N_i^2 \text{ and } p_k = p' \} \]
    Compute another priority \( p''_k \) as follows:
    \[ p''_k = \text{Rand}(k \oplus t \oplus t') \oplus k, k \in M_i \cup \{i\} \]
12. Exit if \( \exists j \in M_i, p''_i \neq p''_j \)
13. Access the common channel in time slot \( t \)

NAMA Algorithm (cont)

Figure 3: Time Division in NAMA

Figure 2: Examples of Collision Types

Further Reading

Comparison

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NAMA, LAMA, PAMA
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Performance
NAMA, LAMA, and PAMA
TRAMA
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Backup
NAMA
TRAMA
Link Activation Multiple Access

- LAMA uses time-slotted code-division multiple access
- There is a pool of quasi-orthogonal pseudo-noise codes, $C_{pn}$
- Receiver, $i$, is assigned code $c_i$ from $C_{pn}$ like so: $c_i = c^k, k = \text{Rand}(i) \mod |C_{pn}|$
- Contenders, $M_i$, are all nodes in the 1-hop and 2-hop neighborhood that use the same code

**LAMA algorithm**

1. Compute the priority $p_k^t$ of every node $k \in M_i \cup \{i\}$ using NCR equation
   $$p_k^t = \text{Rand}(k \oplus t) \oplus k, \quad k \in M_i \cup i$$

2. If NCR equation, $\forall j \in M_i, p_j^t > p_i^t$, holds,
   then activate link $(i, j), j \in n_{i,c}^t$ in time slot $t$

**Figure 6: An Example of Contending Resolution**
Pairwise Activation Multiple Access

- In both NAMA and LAMA contending entities were nodes
- In PAMA, the contending entities are links
- PAMA uses quasi-orthogonal pseudo-noise codes like LAMA, but they are computed for transmitter-receiver pairs
- PAMA is also time-slotted like NAMA and LAMA
- I won’t go into the details of PAMA in the slides
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TRAMA Overview

Random access mode
- Permits node additions/deletions
- Contention based access
- Sized according to how dynamic and number of nodes
- Neighbor Protocol runs in this mode

Scheduled access mode
- Adaptive Election Algorithm
- Schedule Exchange Protocol
- Data transfer

Figure 1: Time slot organization
TRAMA
One of Three Building Blocks: Neighbor Protocol

<table>
<thead>
<tr>
<th>Type</th>
<th>SourceAddr</th>
<th>DestAddr</th>
<th>DeleteNum</th>
<th>AddNum</th>
<th>Deleted NodeID’s</th>
<th>Added NodeID’s</th>
</tr>
</thead>
</table>

(a) Signal Header

<table>
<thead>
<tr>
<th>Type</th>
<th>SourceAddr</th>
<th>DestAddr</th>
<th>Timeout</th>
<th>NumSlots</th>
<th>Bitmap</th>
</tr>
</thead>
</table>

Short Schedule Summary

(b) Data Header

Figure 2: Signaling and data packet header format

- Gathers neighborhood information by exchanging signaling packets.
- Neighbor information exchanged incrementally
TRAMA
One of Three Building Blocks: Schedule Exchange Protocol

1. SCHEDULE_INTERVAL determined from application
2. Node computes winning slots (highest priority among 2-hop neighbors)
3. Node announces receivers for the slots or gives up vacant slots (Bitmap scheme easily allows broadcast and multicast)
4. Last slot in interval is reserved for broadcasting next interval’s schedule
TRAMA
One of Three Building Blocks: Adaptive Election Algorithm

- Node $u$’s priority at time $t$ determined by:
  $\text{prio}(u, t) = \text{hash}(u \oplus t)$

- This priority is used by the SEP to determine which are the winning slots

- At any given time slot $t$, node $u$ is in:
  - TX if $u$ has highest priority in 2-hop hood and has data to send
  - RX if it is intended receiver of the current transmitter
  - SL otherwise
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Figure 2. Time slot organization in DYNAMMA

- Dynamically adapts to traffic patterns
- Collision-free multi channel operation
- Minimum signaling overhead
DYNAMMA
Functional Elements

Traffic and Neighbor Discovery

- Happens in signaling slots (all nodes are awake then)
- Signaling packet holds:
  - Superframe ID
  - Location of signaling slot within superframe
  - One-hop neighborhood information
  - Traffic information

Distributed Scheduling Algorithm

1. Gather active contending flows for this timeslot
2. Compute flow priorities
3. Examine and schedule flows starting at highest priority
4. ...rather involved algorithm - see paper for details
Traffic classification

Classify flows based on:
- Number of packets in the queue.
- Average service rate in the previous superframe.
- Average arrival rate in the previous superframe.

Class 0: Contends for all access slots
Class 1: Contends for 50% of slots
Class 2: Contends for 25% of slots

Figure 3. Traffic classification

Flows are put into the 3 classes depending on their arrival and service rates.
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Differences and Similarities between TRAMA, FLAMA, and DYNAMMA

Figure 1. Various approaches in MAC time slot organization
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Overall Comparison
NAMA, LAMA, and PAMA performance

Fully-connected Network

Figure 9: Average Packet Delays In Fully-Connected Networks

Figure 10: Packet Throughput Of Fully-Connected Networks
NAMA, LAMA, and PAMA performance
Multi-hop Network

Figure 11: Average Packet Delays In Multihop Networks

Figure 12: Packet Throughput Of Multihop Networks
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Synthetic Traffic
Delivery Ratio and Queuing Delay

Figure 7: Average packet delivery ratio for synthetic traffic

Figure 8: Average queuing delay for synthetic traffic
Synthetic Traffic

Energy savings

Figure 9: Energy savings and average sleep interval for synthetic traffic
Figure 6: Data gathering application

Figure 10: Corner Sink
Sensor Scenario
Center and Edge Sinks

(a) Average delivery ratio

(b) Average queuing delay

Figure 11: Center Sink

(a) Average delivery ratio

(b) Average queuing delay

Figure 12: Edge Sink
Sensor Scenario

Energy Savings

![Graphs showing percentage energy savings and average sleep interval for sensor scenarios](image)

**Figure 13:** Energy savings and average sleep interval for sensor scenarios
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Synthetic and Data Gathering Traffic

Average Delivery Ratio and Queuing Delay

Figure 7. Synthetic Traffic

Figure 8. Data Gathering
Synthetic and Data Gathering Traffic

Energy Savings

Figure 9. Energy Savings
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Further Reading

Lichun Bao and J. J. Garcia-Luna-Aceves.
A new approach to channel access scheduling for ad hoc networks.

Venkatesh Rajendran, Katia Obraczka, and J Garcia-Luna-Aceves.
Energy-efficient collision-free medium access control for wireless sensor networks.

Venkatesh Rajendran, K Obraczka, and JJ Garcia-Luna-Aceves.
Dynamma: A dynamic multi-channel medium access framework for wireless ad hoc networks.
**NAMA**

Frame Formats

![Diagram of Time-slot and Segment](image)

**Figure 4: Signal Frame Format in Membership Section**

![Diagram of Regular Data Frame](image)

**Figure 5: Data Frame Format in Regular Sections**
TRAMA

Signaling and Data Packet Header Format

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<th>Bitmap</th>
</tr>
</thead>
</table>

| Short Schedule Summary |

( b) Data Header

Figure 2: Signaling and data packet header format
## TRAMA

### Schedule packet format

<table>
<thead>
<tr>
<th>Field</th>
<th>SourceAddr</th>
<th>Timeout</th>
<th>Width</th>
<th>NumSlots</th>
<th>Bitmaps</th>
<th>.......</th>
<th>.......</th>
<th>Width x Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Size (bits)</td>
<td>32</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>Width x Size</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Bitmap (Width = 4)**

<table>
<thead>
<tr>
<th>1 0 1 0</th>
<th>0 0 1 0</th>
<th>0 0 0 0</th>
<th>0 0 0 0</th>
</tr>
</thead>
</table>

- **Reserved for particular set of receivers depending on the node traffic.**
- **Does not have data, these slots could be used by other one-hop neighbors with data.**
- **Reserved for announcing the schedule.**

![Figure 3: Schedule packet format](image-url)

**Figure 3: Schedule packet format**