Efficient Multi-Receiver Message aggregation for Short Message Delivery in M2M Networks

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Wireless M2M Networks

✓ Environment monitoring
✓ Transportation system
✓ Manufacture management
✓ Power grid, Smart grid
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Massive End Devices!
Messages are short!
The Communication Efficiency

• Communication efficiency can be affected by
  – Protocols overhead
  – Channel access strategy
  – Requirements on reliability: ARQ

• Current solutions
  • Most focus on relieving collision in contention-based channel access
  • For protocol overhead: from view of point-to-point link, such as packets aggregation
Objective & Contribution

• Our Objective
  – To reduce protocol overhead for point to multiple point communications in wireless M2M networks.

• Our contributions
Objective & Contribution

• Our Objective
  – To reduce protocol overhead for **point to multiple point** communications in wireless M2M networks.

• Our contributions

- The **MRMA** protocol, including
  - An **Multi-Receiver Message Aggregation** scheme
  - A **Busy-Tone based Negative-ACK** scheme
  - Performance Optimization: to reduce the per-message overhead
The MRMA Protocol

- Multi-receiver message aggregation (MRMA):

(a). Unicast:

<table>
<thead>
<tr>
<th>Packet Header</th>
<th>Msg</th>
<th>CRC</th>
</tr>
</thead>
<tbody>
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<td>(N_h) bits</td>
<td>(N_{Msg}) bits</td>
<td>(N_e) bits</td>
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(b). Aggregation Broadcast:

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\((n\text{ Messages})\text{ in Total}\)
The MRMA Protocol

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**Per-Message Overhead (PMO)**

\[
PMO = \frac{R(\text{Header+CRC}) + (R - 1)\, Msg}{\text{No. of Msg}}
\]

**Ratio**

\[
\text{Ratio} = \frac{\text{PMO of Broadcast}}{\text{PMO of Unicast}}
\]

Good enough?
The MRMA Protocol

- Multi-receiver message aggregation (MRMA):

(a) Unicast:

(b) Aggregation
Broadcast:

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Insights:

1. Overhead using aggregation can be larger than that without it
2. There exists an “optimal” aggregation configuration
Multi-receiver message aggregation (MRMA) Scheme:

1. Introducing “Error Detection Code (EDC)” - avoiding unnecessary retransmissions
2. Limiting the no. of messages being aggregated - reducing the protocol overhead

The MRMA Protocol

EDC is similar to CRC, but with different purpose.

Proposing:

1. Introducing “Error Detection Code (EDC)”
   - avoiding unnecessary retransmissions
2. Limiting the no. of messages being aggregated
   - reducing the protocol overhead
The MRMA Protocol

• Busy-Tone NACK Scheme
The MRMA Protocol

- Busy-Tone NACK Scheme

**Advantages:**
- Shorter acknowledgement time
- Improving the efficiency in acknowledgment
- Better ACK signal quality
- Improving the communication reliability
Performance Optimization

– The key issue to obtain efficiency gain is
  • the number of messages aggregated in one packet
– Model of “Cost” in a K-Message-Aggregation

**Metric:** channel occupation time

\[
C(M_K) = \frac{C_h(1 + \eta K)}{K} \cdot E[r(M_K)]
\]

\[
E[r(M_K)] = \sum_{r=1}^{R} \left[ 1 - \prod_{i \in M_K} \left( 1 - m_i^{r-1} \right) \right]
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Performance Optimization

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Performance Optimization

– Optimal Configuration to reduce the cost when given N messages
  ➢ How many aggregated packets?
  ➢ How to assign messages?

– An integer programming problem
  ➢ to maximize the difference in cost between using Unicast and MRMA

\[
\text{Max: } \sum_{g=1}^{G} \sum_{r=1}^{R} \left\{ C_h(1 + \eta) \sum_{i=1}^{N} \phi_{ig} p_i^{r-1} - C_h(1 + \eta |\mathcal{M}_g|) \left[ 1 - \prod_{i=1}^{N} (1 - \phi_{ig} m_i^{r-1}) \right] \right\},
\]

\[
\text{s.t.: } \sum_{g=1}^{G} \phi_{ig} = 1, \quad \phi_{ig} \in \{0, 1\}, \quad 1 \leq G \leq N.
\]
Performance Optimization

– Optimal Configuration to reduce the cost when given N messages
  ➢ How many aggregated packets?
  ➢ How to assign messages?
– Two integer programming problems
  ➢ to maximize the difference in cost between using Unicast and MRMA

\[
\begin{align*}
\text{Max:} & \sum_{g=1}^{G} \sum_{r=1}^{R} \left\{ C_h(1 + \eta) \sum_{i=1}^{N} \phi_{ig} p_i^{r-1} - C_h(1 + \eta |\mathcal{M}_g|) \left[ 1 - \prod_{i=1}^{N} (1 - \phi_{ig} m_i^{r-1}) \right] \right\}, \\
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\end{align*}
\]
Performance Optimization

– Proposing efficiency optimization algorithms

✓ A heuristic algorithm
  ✓ Step 1: an offline table for optimal (local) aggregation size “K-BER” in homogeneous MER case;

✓ Step 2: A greedy algorithm for the heterogeneous MER case.

✓ Complexity: $O(N)$

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**Algorithm 3 Greedy algorithm for heterogeneous BER case**

| Input: $\{R, p_i, m_i, N\}$, |
| 1: Sorting all receivers descendant according to $m_i$, $\mathcal{M} = \{m_i\mid i = 1, 2, \ldots, N\}, g = 1.$ |
| 2: while $\mathcal{M} \neq \emptyset$ do |
| 3: Searching item $\{m_1, n^*\}$ in the Opt-Aggregation table, |
| 4: $\mathcal{M}_g = \{m_1, \ldots, m_{n^*}\}, \mathcal{M} = \mathcal{M} \setminus S_g, g = g + 1,$ |
| 5: end while |
| 6: $G = g,$ |
| Output: $\{\mathcal{M}_g\}$ $(g = 1, 2, \ldots, G).$ |
Performance Evaluation

• Numerical Results:
  – Performance metric: per-message overhead

Homogeneous BER case

Heterogeneous BER case
BER ∈ (0, 10^{-2})

MRMA can achieve about 40% efficiency gain over Unicast
Summary

➢ To improve the efficiency for point to multi-point communications,

✓ we proposed a Multi-Receiver Message Aggregation Protocol, including
  ✓ the message aggregation scheme,
  ✓ transmission acknowledgement scheme;

✓ optimization problem were formulated and algorithms were proposed for “optimal” aggregation configuration.
Thanks!

Questions/Comments?

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