An Energy-efficient 2R MAC based on IEEE 802.15.6 for Health Monitoring

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Introduction

- Health monitoring
  - Data arrives in different ways under different scenarios
  - Heterogeneous data arrival rate
  - Correlation between sensor nodes

Fig. 1 System structure of health monitoring
Introduction

• Designing MAC protocol for health monitoring: extreme-low power and high reliability.

• Problems in existing works
  – Contention-based MACs: idle-listening, overhearing and frequently collisions cost too much unnecessary energy.
  – Scheduled-based MACs: failed in adapting the heterogeneous data arrival rate in health monitoring
  – Hybrid-based MACs: high overhead

• Solution
  – Two round reservation MAC (2R-MAC)
Introduction

• The contributions of this paper are:

  – According to the characteristics of data in health monitoring, 2R MAC classifies data into periodic data and burst data. Two round reservations are constructed respectively to fully utilize the advantages of scheduled scheme.

  – Building a relationship between the appropriate number of allocation slots and the heterogeneous data arrival rate, which helps utilize the time resource more efficiently.

  – Hub determines the transmission order of nodes with burst data based on a new factor by considering the correlation between sensor nodes.
IEEE 802.15.6

- IEEE 802.15.6 is an international standard for short-range, wireless communications in the vicinity of, or inside, a human body.
  - Three access modes
    - Beacon mode with superframes.
    - Non-beacon mode with superframes
    - Non-beacon mode without superframes
  - Five access method
    - Random Access, Improvised Access
    - Unscheduled Access, Scheduled Access, Scheduled-polling Access

Fig. 1 Superframe structure of the beacon mode with superframes

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Two round reservation scheme

1. Superframe structure

- **Beacon**: declare the information related to BAN identification, synchronization and superframe structure.
- **First round reservation period**: transmit the periodic data and raise the second round reservation if burst data occurs.
- **Second round reservation period**: transmit the burst data.
- **Sleep period**: hub and node enters sleep mode when there is no data to save energy.

Fig. 3 superframe structure of proposed protocol
Two round reservation scheme

- 2. First round reservation
  - Conducted once the node joins in a specific WBAN.
  - Adding the necessary description about health monitoring into connection management frame.

Fig. 4 The first round reservation procedure

Fig. 5 First Round Allocation Reservation frame

Fig. 6 First Round Allocation Assignment frame
Two round reservation scheme

• 3. Second round reservation
  – Aiming to handle both the burst streams and guarantee lower delay for nodes with higher user priority and critical conditions.
  – Second round reservation is conducted once the node has burst data.

Fig.7 Second Round Allocation Request frame
Two round reservation scheme

3. Second round reservation
   - User Priority (UP)
     In accordance with IEEE 802.15.6, sensor node is classified into eight Up, which varies from UP0 to UP7.
   - Health Severity Index (H)
     \[
     H = \begin{cases} 
     \min\left(\frac{\theta_l - \theta}{\theta_u - \theta_l}, 1\right) & \theta \leq \theta_l \\
     0 & \theta_l \leq \theta \leq \theta_u \\
     \min\left(\frac{\theta - \theta_u}{\theta_u - \theta_l}, 1\right) & \theta \geq \theta_u 
     \end{cases}
     \]
   - Token
     Hub determines the transmitting order of nodes with burst data. Nodes with higher \textit{token} are awarded with the higher privilege to transmit.
     \[
     \text{token} = \rho_1 \times \frac{UP}{8} + \rho_2 \times H \\
     \text{s.t.} \quad 0 \leq \rho_1, \rho_2 \leq 1, \quad \rho_1 + \rho_2 = 1
     \]
Dynamic time slot allocation

- Since sensors nodes in health monitoring own heterogeneous data arrival rates, it is necessary to assign the appropriate allocation interval for each node according their data arrival rate.

$$t_{interval} = (k - 1) \times t_{packet} + t_{RemainPacket} + k \times (pSIFS + t_{ACK}) + pSIFS + GT + t_{prodelay}$$

$$k = \left\lceil \frac{\lambda_i \times t_{superframe}}{N_{MACFrameBody}} \right\rceil$$

1-periodic

$$k = \left\lceil \frac{\lambda_i \times m \times t_{superframe}}{N_{MACFrameBody}} \right\rceil$$

m-periodic

$$t_{packet} = \frac{N_{preamble} + N_{header} \times S_{header} + N_{total} \times S_{PSDU}}{\log_2 M}$$

Symble rate

$$N_{AllocationSlot} = U \times \left\lceil \frac{t_{interval}}{AllocationSlotLength} \right\rceil$$

U denotes the scaling up factor which should be determined by considering the channel condition, interference from other nodes and delay of hardware processing.
Two round reservation scheme

• An example of 2R MAC

Fig. 9 Two round reservation scheme

Periodic Data arrival rate: Node A > Node C > Node B
Token of burst data: Node A < Node C
Simulation analysis

- Simulation scenario

There are eight nodes and a hub in the network, each node generate periodic data with data arrival rate varies from 1 kbps to 8 kbps.

- Simulation parameters

<table>
<thead>
<tr>
<th>Voltage Supply</th>
<th>3 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit current  ($I_{tx}$)</td>
<td>7.5 mA</td>
</tr>
<tr>
<td>Receive current ($I_{rx}$)</td>
<td>13.1 mA</td>
</tr>
<tr>
<td>Standby current ($I_{idle}$)</td>
<td>26 uA</td>
</tr>
<tr>
<td>Sleep current ($I_{sleep}$)</td>
<td>900 nA</td>
</tr>
</tbody>
</table>

$$E_{state} = V_{state} * I_{state} * t_{state}$$
Simulation analysis

- Energy efficiency

![Energy efficiency vs. number of nodes with burst data](image)

Fig. 10 Energy efficiency vs. number of nodes with burst data
Simulation analysis

- Energy consumption
  - Nodes No.1-4 have burst data while other not

Fig. 11 Energy consumption vs. node number

IEEE 802.15.6
1R MAC
2R MAC

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Simulation analysis

• Lifetime

\[ E_{\text{node}} = \frac{E_{\text{WithoutBurst}} + E_{\text{WithBurst}}}{2} \]

\[ \text{lifetime} = \frac{Q}{E_{\text{node}}} \times t_{\text{superframe}} \]

![Lifetime vs. node number](image)

Fig. 12 Lifetime vs. node number
Conclusion

- Conclusion
  - conducts two round reservation for periodic data and burst data in health monitoring, respectively.
  - builds a relationship between the appropriate number of allocation slots and data arrival.
  - introduces a new factor- *token* to help hub determine the transmission order of nodes with burst data.
  - prolongs the lifetime of sensor nodes up to 31.35% and 12.01%.

- Future work
  - calculates the appropriate number of allocation slots for nodes based on the ideal channel assumption. However, the body channel is much more complex that we would take this part into account in the future work.
Thank you