Source Traffic Modeling in Wireless Sensor Networks for Target Tracking

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Traffic within WSN – How much do we know about it?

• A fact:
  – too much talk about traffic in WSN, but too few understanding about it.

• Why?
  – The specialty of WSN renders the existing insights on traditional network traffic less useful.
  – Because traffic in WSN is highly application dependent, and people do not know where to start.
Traffic scenario categorization for WSN

• Periodically reporting
  – HELLO message, routing message exchange
  – Applications like temperature monitoring, video surveillance system

• Event-driven transmission
  – Reporting any feature with 0-1 outcome
  – Applications like target tracking, where the detection of the target is an interesting event
Traffic modeling for WSN

• Periodically reporting
  – Constant Bit Rate (CBR)

• Event-driven transmission
  – Poisson?
  – Bursty traffic
ON/OFF model – state transition diagram

- OFF to ON: New traffic observed
- ON to OFF: ON timer expired
- ON to ON: ON timer refreshed due to the following traffic observation
ON/OFF Model – a paradigm

ON timer length: 5 sec
An event-driven scenario – WSN for target tracking

• Targets move around in the WSN deployment area

• Target is detected when it enters into the nearby region of a sensor node

• Traffic burst arises from a sensor node when a concerned target stays in its sensing range

• The time duration for a traffic burst corresponds to an ON period in the ON/OFF model
Traffic modeling – WSN for target tracking

• Goal:
  – in order to give insights about traffic characters in event-driven WSN scenarios

• Methods:
  – By carrying simulations in a modified ns-2 ([http://apachepersonal.miun.se/~qinwan/resources.htm](http://apachepersonal.miun.se/~qinwan/resources.htm))
  – Capturing traffic bursts using ON/OFF model
  – Fitting ON/OFF period distributions to get insights
Traffic modeling – WSN for target tracking

• Simulation settings:
  – Nodes number: 100
  – Deployment area: 1000m×1000m
  – One sink: located in the center
  – One target: randomly moving around
  – Sensing range: ~250m
  – Communication range: ~250m
  – Routing: multi-hop AODV protocol
Traffic modeling – WSN for target tracking

Distribution of target observation probability:
Results – ON period distribution

PDF plot of the statistical ON period distribution for node-edge

Statistical distribution (5s ON timer)
Results – ON period distribution

CDF plot of ON period distributions for node-edge

Cumulative probability

ON period length (sec)

Statistical distribution (1.5s ON timer)
Statistical distribution (5s ON timer)
Statistical distribution (20s ON timer)
Results – ON period distribution

CDF plot of ON period distributions for node-center

Statistical distribution (1.5s ON timer)
Statistical distribution (5s ON timer)
Statistical distribution (20s ON timer)
Results – OFF period distribution

PDF plot of the statistical OFF period distribution for node-edge

Statistical distribution (5s ON timer)
Results – OFF period distribution

CDF plot of OFF period distributions for node-edge

- Statistical distribution (1.5s ON timer)
- Statistical distribution (5s ON timer)
- Statistical distribution (20s ON timer)
Results – OFF period distribution

CDF plot of OFF period distribution for node-center

- many_off data 1.5s
- many_off data 5s
- many_off data 20s
ON/OFF period distribution fitting

• Generalized Pareto distribution
  – Probability density function:
    \[ y = f(x | k, \sigma, \theta) = \left(\frac{1}{\sigma}\right)(1 + k \frac{x - \theta}{\sigma})^{-1 - \frac{1}{k}}, \quad \theta < x \]
  – Useful property:
    \[ \theta < x < -\frac{\sigma}{k} \text{ (short tail), if } k < 0 \]
ON/OFF period distribution fitting

Fitted ON period distribution for node-edge
ON/OFF period distribution fitting

Fitted ON period distribution for node-center
ON/OFF period distribution fitting

Fitted OFF period distribution for node-edge

Cumulative probability

OFF period length (sec)

- Statistical distribution (1.5s ON timer)
- Fitted distribution (1.5s ON timer)
- Statistical distribution (5s ON timer)
- Fitted distribution (5s ON timer)
- Statistical distribution (20s ON timer)
- Fitted distribution (20s ON timer)
ON/OFF period distribution fitting

Fitted OFF period distribution for node-center
## Parameters used in fitting ON/OFF period distributions with GPD

<table>
<thead>
<tr>
<th>nodes</th>
<th>Fitted ON period distribution</th>
<th>Fitted OFF period distribution</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>node-edge</td>
<td>node-center</td>
</tr>
<tr>
<td>ON timer</td>
<td>1.5s 5s 20s</td>
<td>1.5s 5s 20s</td>
</tr>
<tr>
<td>$k$</td>
<td>$k &lt; 0$</td>
<td>$k &lt; 0$</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>5.05 4.77 19.99</td>
<td>51 84 654</td>
</tr>
<tr>
<td>$\theta$ (sec.)</td>
<td>1.49 4.99 19.99</td>
<td>1.49 1.49 1.49</td>
</tr>
<tr>
<td>$x \mid F(\text{Period} \leq x) = 0.99$ (sec.)</td>
<td>16.7 22.3 45.5</td>
<td>51 84 654</td>
</tr>
<tr>
<td>Mean (sec.)</td>
<td>5.703 9.291 24.96</td>
<td>14.39 23.53 144</td>
</tr>
<tr>
<td>$\frac{x}{\text{Mean}}$</td>
<td>2.93 2.40 1.82</td>
<td>3.54 3.57 4.53</td>
</tr>
</tbody>
</table>

### Short-tail property

- $k < 0$
- $x < 3 \times \text{Mean}$
Why “short-tail property” is good?

- If traffic exhibits “short-tail property”, an observed unusually long ON period may indicate an energy exhaustion attack.
- If traffic exhibits “short-tail property”, an observed unusually long OFF period can indicate a node failure.
- With “short-tail property”, we can identify these abnormal periods with high confidence at early time (by waiting less than 5 times of the mean period duration in the above scenario).
Conclusions

• We present a traffic modeling for an event-driven sensor network scenario – target tracking

• ON/OFF model is found to be suitable for capturing the bursty nature of event-driven sensing traffic

• The statistical distributions of ON and OFF periods are found to follow the generalized Pareto distribution very well

• The OFF period distribution is found to be insensible to the choice of ON timer, which could be some kind of self-similarity.

• Both ON and OFF period distributions exhibit “short-tail property”, which means the abnormal ON/OFF period can be identified quickly.
Thank you!