Routing for IoT and Sensor Systems

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The Collection Tree Protocol (CTP)

Omprakash Gnawali, Rodrigo Fonseca, Kyle Jamieson, David Moss, and Philip Levis
Collection Tree Protocol
In Proceedings of SenSys’09, November 2009
In a WSN the sensed data are collected by a small number of base stations, called sinks.

Nodes don’t need routes towards all the other network nodes.

- Just to one sink (anycast communication).

The routing protocols designed for this problem are called Collection protocols.
The Collection Tree Protocol (CTP)

• The Collection Tree Protocol is widely considered as the main routing protocol for data collection.

• It builds and maintains one or more routing trees, each one rooted in a sink.

• Every node “belongs” to a routing tree and select one of its neighbors as its parent.

• Parents handle packets received from children nodes and further forward them towards the sink.
• CTP is a distance vector protocol

• The metric is the Expected number of Transmissions to reach the sink (ETX)

• The ETX of a node depends on:
  • distance in hops from the sink
  • Quality of the communication links
CTP: architecture

- **Control Plane**
  - Routing Engine
  - Link Estimator

- **Data Plane**
  - Forwarding Engine
  - Routing Engine

- **Link Layer**
  - Send and receive beacons for tree construction and maintenance
  - Create and update the routing table

- **Application Layer**
  - Forwards packets
  - Detects and repairs loops
  - Filters duplicate packets

- **Routing Table**
  - Create and update the routing table
CTP: packet frames

Routing Frame

<table>
<thead>
<tr>
<th>PC</th>
<th>Reserved</th>
<th>Parent</th>
<th>ETX</th>
</tr>
</thead>
</table>

16 bits

Data Frame

<table>
<thead>
<tr>
<th>PC</th>
<th>Reserved</th>
<th>THL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Route ETX</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Origin</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Seq. No.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Collect ID</td>
</tr>
</tbody>
</table>

16 bits

Fig. 7 (Top) CTP routing frame format. (Bottom) CTP data frame format.

Routing

CTP: packet frames
CTP: Parent selection

• Every node needs to assess the quality of the communication links with its neighbors (ETX_{1-hop}).

  • Outgoing link: percentage of acknowledged data packets

  • Ingoing link: percentage of beacon received by the neighbor.

• The ETX via a given neighbor is the sum of ETX_{1-hop} and of the ETX announced by the neighbor with its beacons.

  • The neighbor with the minimum sum is chosen to be the parent.
CTP: Datapath validation

- Datapath validation is how CTP tries to fix routing inconsistencies.
- The next hop should be closer to the sink.
  - The ETX should decrease.
- Because of stale routing information, it can happen that a node sends a packet to a neighbor with a higher ETX.
CTP: Datapath validation (2)

- Every data packet contains the transmitter’s ETX.

- When a node receives a packet, it compares the transmitter’s ETX with its own.

- If it is not greater than the receiver’s ETX:
  - the receiver forwards the packet (to check if there are other inconsistencies)
  - the receiver increase the beacon transmission rate (trying to send updated information to neighbors with stale routes).
CTP: adaptive beaconing

• It is how CTP manage the beacon transmission interval.
• When the topology is stable sending beacon at a high rate is a waste of energy.
  • We can increase the interval.
It extends the Trickle Algorithm:

• Start with a small interval: $t_{\text{min}}$.

• Double the interval up to $t_{\text{max}}$.

• Reset to $t_{\text{min}}$ when inconsistency is detected.
ALBA-R: a cross-layer integrated protocol stack for medium-large scale Wireless Sensor Networks

Chiara Petrioli, Michele Nati, Paolo Casari, Michele Zorzi, Stefano Basagni
ALBA-R: Load-Balancing Geographic Routing Around Connectivity Holes in Wireless Sensor Networks
IEEE Transactions on Parallel and Distributed Systems, March, 2014
Geographic routing

• **Idea**: Forward the packet to a node that is geographically closer to the sink.

• **Pros**:  
  • Virtually stateless (needs only knowledge of source’s and destination’s locations)

• **Cons**:  
  • Requires position estimation  
  • Dead ends.
Geographic routing: dead ends

• In this example, a route to the sink is available, but the packets get stuck at the current relay.
  • There are no nodes in the positive advancement area
  • The next hop is not the geographically closest.
• We need to “push back” the packet.
ALBA-R

- ALBA: Adaptive Load-Balancing Algorithm
- Cross-layer protocol
  - MAC (the nodes follow a fixed duty-cycle)
  - Geographic routing
  - Load balancing the traffic among nodes
  - Scheme to deal with dead ends (Rainbow)
ALBA

- Nodes forward packets in bursts (up to $M_B$ packets)
  - The length of the burst is variable
- The forwarder is elected considering:
  - The ability to handle correctly forwarded packets (Queue Priority Index, QPI)
  - Geographic proximity to the sink (Geographic Priority Index, GPI)
ALBA (2)

\[ QPI = \left\lfloor \frac{Q + N_B}{M} \right\rfloor - 1 \]

Queue level

Requested length of the burst

Average length of a burst the relay expects to transmit correctly

\[ QPI = \text{Queue Priority Index} \]

\[ GPI = \text{Geographic Priority Index} \]
• The metric used for the choice of the relay ensures load balancing because it chooses relay with:
  • Low queue, especially if $N_B$ is high
  • Good forwarding history (through $M$)
ALBA: relay selection

- Phase 1: Selection of the best QPI
  - Attempt 1 search for QPI=0, Attempt 2 for QPI=0,1 and so on
  - Awaking nodes can participate in this phase
- Phase 2: Selection of the best GPI
  - Tie-breaking if more than one node have the same QPI
  - Awaking nodes cannot participate (to speed up completion)
1) Node A is nearer to the sink (GPI=1) but has a low QPI (M=2); node B, is farther but is more reliable (M); B has a better QPI than A
2) If Node B is asleep when the RTS is sent, node A is elected as forwarder
ALBA-R: Rainbow

- A node coloring algorithm for routing out of dead ends and around connectivity holes.
- Idea: allow the nodes to forward packets away from the sink
In order to remember whether to seek for relays in the direction of the sink (positive advancement area $F$) or in the opposite direction (negative advancement area $F^C$) each node is labeled with a color (from a given list).

Each node seeks for relays among nodes with its own color or with the preceding color (in the list)
6LoWPAN
6LowPAN

- IPv6 over Low power WPAN (6LoWPAN) is an adaptation layer that allows to route Internet traffic over WSNs.

- Why do we need an adaptation layer?
  - IEEE 802.15.4 is the typical protocol stack for Physical Layer and Data Link Layer for WSNs.
    - Its payload is limited to 127 bytes.
    - IPv6 minimum packet size is 1280 bytes!
It uses two strategies:

- Header compression: redundant information in IPv6 header is removed.
- Fragmentation: split the packets into multiple smaller sub-packets.
6LoWPAN: Fragmentation Header

- When an IPv6 packet is split into multiple chunks, 6LoWPAN adds a Fragmentation Header to allow its reconstruction.

- It has the following fields:
  - Datagram size: dimension of the entire IP packet before fragmentation
  - Datagram Tag: identifies univocally the original fragmented IP packet.
  - Datagram Offset: specifies of the offset of the fragment from the beginning of the packet.
6LoWPAN: Header compression

- 6LoWPAN tries to remove from the IPv6 packet header all the fields that can be derived from other headers (added by other protocol stack layers).

- For example:
  
  - interface addresses are formed with an *Interface Identifier* derived directly from the MAC address.
  
  - The first 64 bit of both source address and destination can be removed if they are carry a link-local prefix.
  
  - The payload length can be inferred from the MAC layer or from the Datagram Size field in the fragmentation header.