B. Gradient field establishment

GLOBAL utilizes the naive flooding-based gradient field establishment algorithm to set up initial gradients of sensor nodes\(^3\). When a network is initialized, each of sinks floods an ADV packet one after another with a pre-defined time interval which is set to enough time to ensure that two consecutive floodings do not interfere with each other. The ADV packet contains the following fields for the gradient field construction. Initially, sinks have the three fields whose values are 0. For example, in Figure 2, when sensor node B rebroadcasts the ADV packet received from sensor node A, \(hcnt\), \(\text{sum\_redr}\) and \(\text{max\_redr}\) carry 2, \(\text{REDRA} + \text{REDRB}\) and \(\max(\text{REDRA}, \text{REDRB})\), respectively. \(\text{REDRA}\) and \(\text{REDRB}\) represent the \(\text{REDR}\) values of sensor nodes A and B, respectively.

- \(hcnt\): The number of hops (or links) that the ADV packet has traversed.
- \(\text{sum\_redr}\): The sum of \(\text{REDR}\) values of sensor nodes that the ADV packet has traversed.
- \(\text{max\_redr}\): The maximum \(\text{REDR}\) value among \(\text{REDR}\) values of sensor nodes that the ADV packet has traversed.

![Fig. 2. The flooding of ADV.](image)

When a sensor node (say, node \(i\)) initially receives an ADV packet, it firstly initializes its all local variables to NULL and its local variables including its gradient are updated through the fields specified in the received ADV packet (see Algorithm 1). When node \(i\) receives an ADV packet for the first time, it increases the \(hcnt\) value appeared in the ADV packet by one in order to account for the new hop distance. \(s\_{\text{hc}}\)nt keeps the increased value (i.e. \(hcnt + 1\)). Since node \(i\) initially does not have any path information, the newly acquired path will be used to transmit data as the shortest hop path. Hence, \(\text{path\_hc}\)nt is set to the same value of \(s\_{\text{hc}}\)nt. Both hop-count variables are used to avoid an excessive increase in the path length as followings. Then, after updating its \(\text{REDRI}\) through the procedure described in Section III.A.1, node \(i\) updates \(\text{sum\_redr}\_L\) and \(\text{max\_redr}\_L\) as shown in Algorithm 1. \(\text{sum\_redr}\_L\) and \(\text{max\_redr}\_L\) indicate the cumulative path load and traffic load of the most overloaded node over the path, respectively. Using Equation (7), node \(i\) calculates its gradient \(G_i\) and maintains \(G_i\) in its local memory.

From the proposed gradient model introduced in Section III.A.2, \(G_i\) is calculated by averaging the two metrics, namely \(\text{sum\_redr}\_L\) and \(\text{max\_redr}\_L\), where \(\beta\) is a weighting factor of both parameters and ranges between 0 and 1. After updating its local variables, node \(i\) updates the fields in the ADV packet from its local variables as follows: \(hcnt=\text{path\_hc}\)nt, \(\text{sum\_redr}=\text{sum\_redr}\_L\), \(\text{max\_redr} = \text{max\_redr}\_L\). Finally, it rebroadcasts the ADV packet.

\[
G_i = \beta \cdot \text{sum\_redr}\_L + (1 - \beta) \cdot \text{max\_redr}\_L
\]  

(7)

After acquiring the initial path, node \(i\) may still discover a less loaded path than the initial path when it receives a duplicate ADV packet. However, since the latency of an end-to-end delivery increases as the number of hops in the path increases, it is not desirable to select a very long path with respect to load balancing. Therefore, GLOBAL defines a system parameter \(K\) in order to prevent a sensor node from selecting an extremely long path. Given paths

\(^3\)Ye et al.[4] proposed an efficient backoff-based gradient field establishment algorithm which attempts to find the optimal costs of all nodes to the sink with the overhead of one packet per node. Although GLOBAL currently utilizes the naive flooding-based gradient field establishment algorithm, it can simply adopt the backoff-based one. The performance improvement issue in the gradient field establishment algorithm is out of scope of this paper.