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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

Collection

- 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.

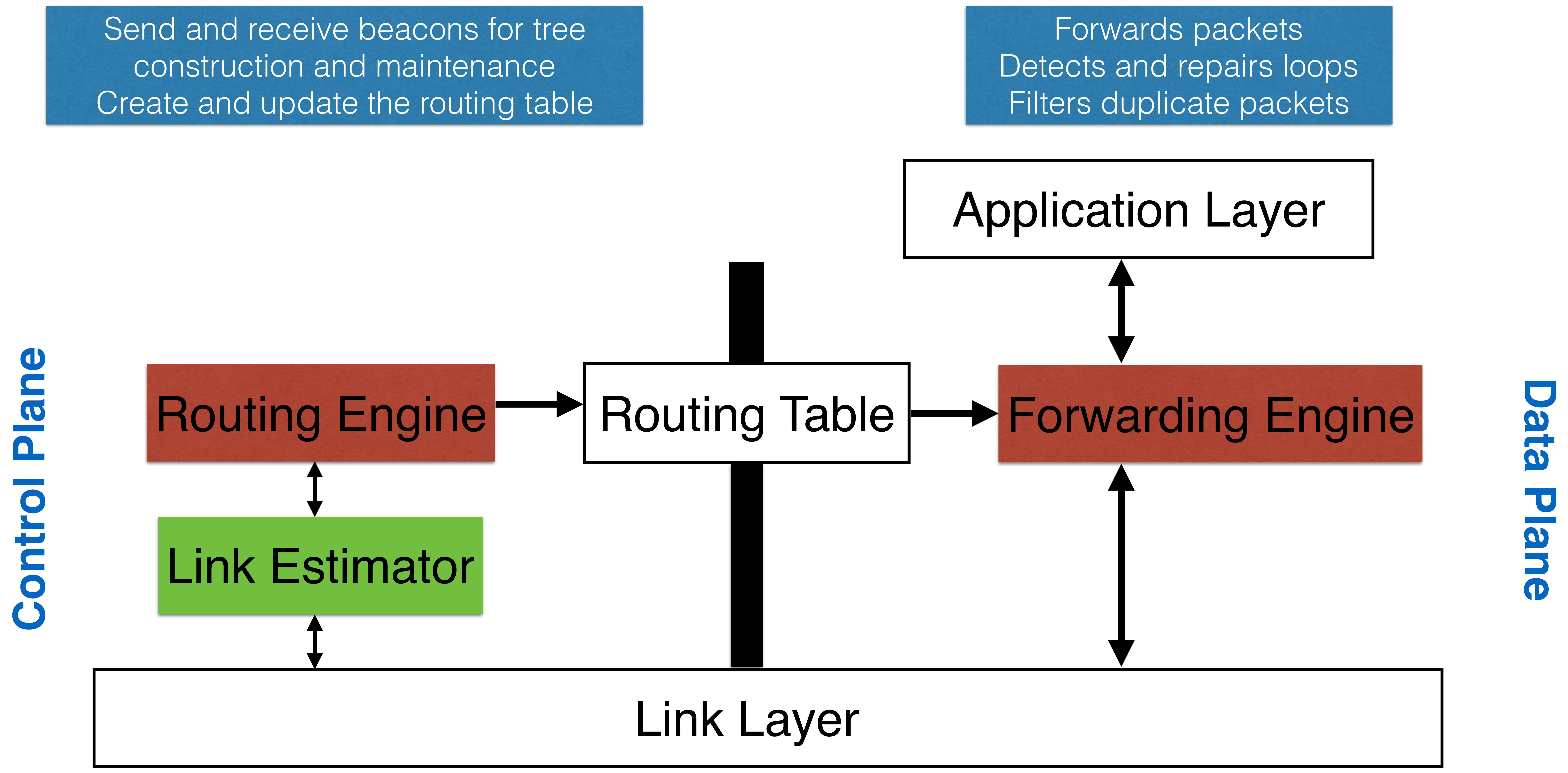
The Collection Tree Protocol (CTP)

- 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 (2)

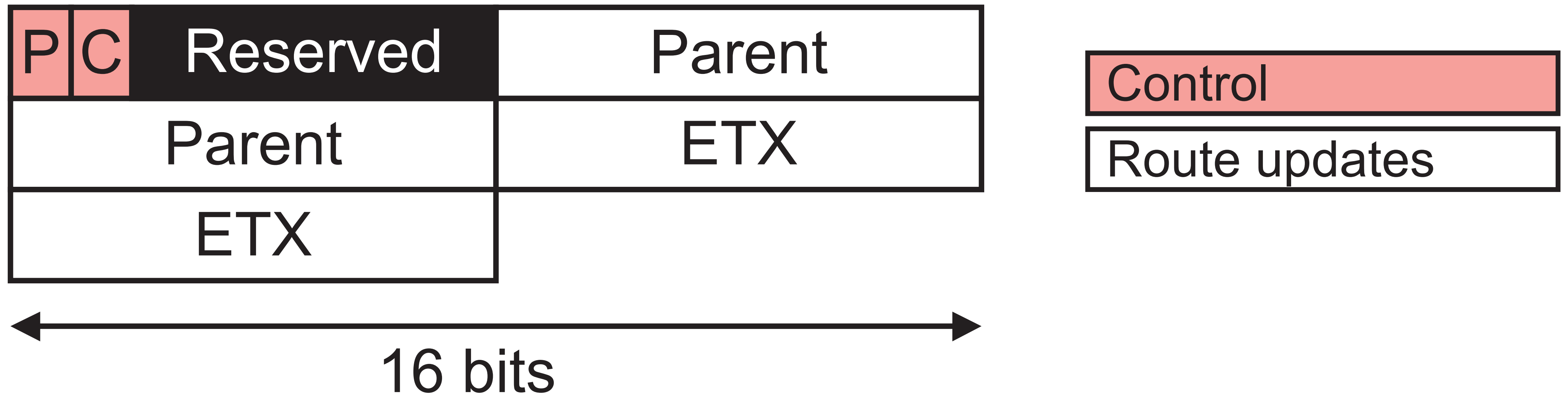
- CTP is a distance vector protocol
- The metric is the Expected number of Transmissions to reach the sink (ETX)
- The ETX of a node depends on:
  - distance in hops from the sink
  - Quality of the communication links

CTP: architecture

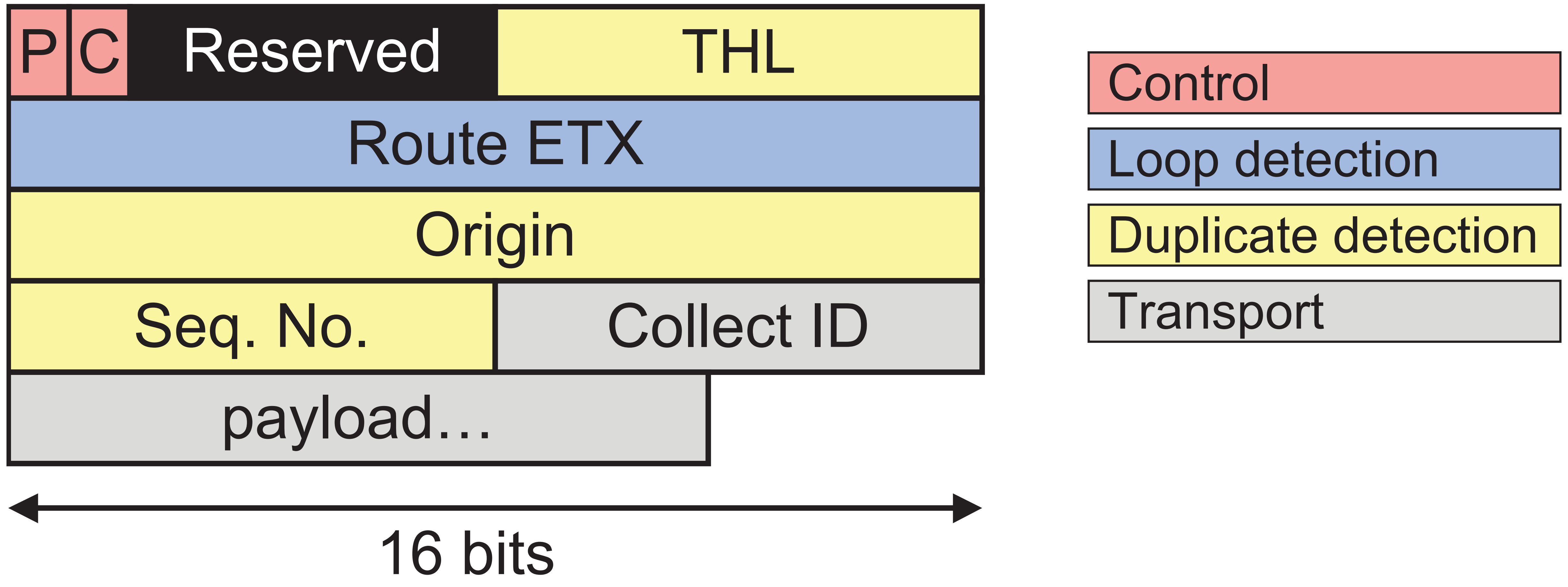


CTP: packet frames

Routing Frame



Data Frame



CTP: Parent selection

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

CTP: adaptive beaconing (2)

It extends the Trickle Algorithm:

- Start with a small interval: $t_{min.}$
- Double the interval up to $t_{max.}$
- Reset to t_{min} when inconsistency is detected.

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ALBA-R: a cross-layer integrated protocol stack for medium-large scale Wireless Sensor Networks

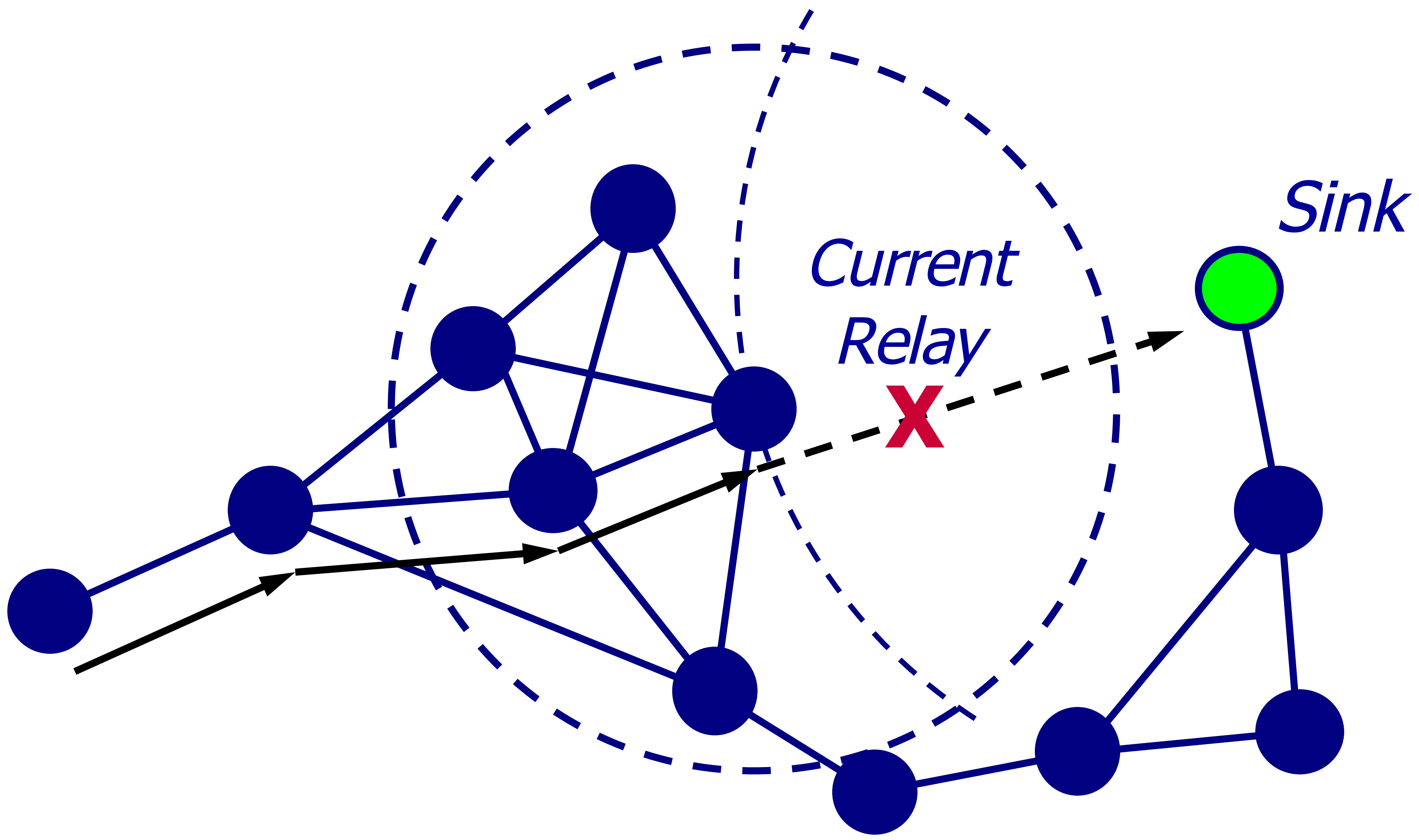
Chiara Petrioli, Michele Nati, Paolo Casari, Michele Zorzi, Stefano Basagni
ALBA-R: Load-Balancing Geographic Routing Around Connectivity Holes in Wireless Sensor Networks
IEEE Transactions on Parallel and Distributed Systems, March, 2014

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.



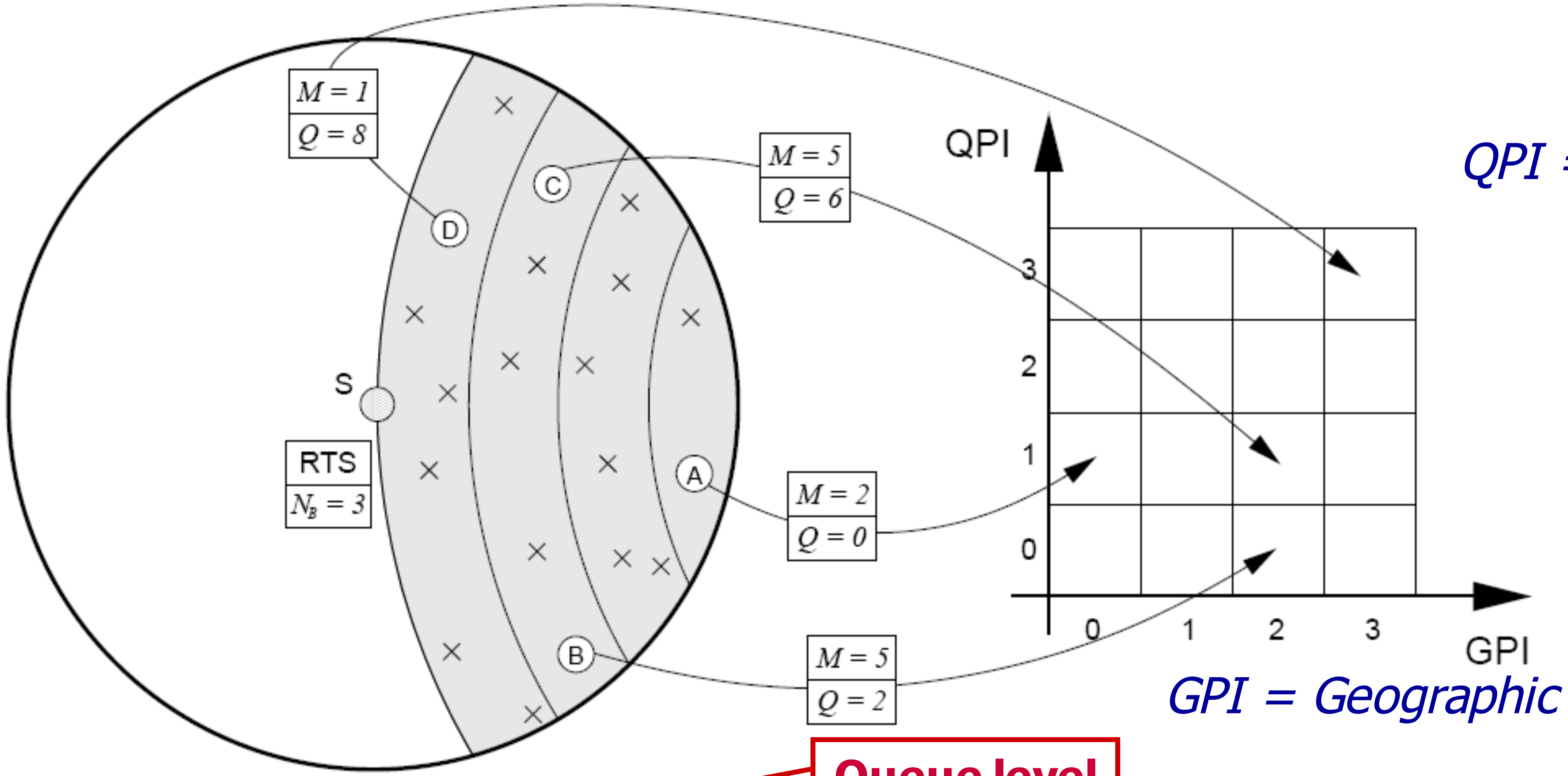
ALBA-R

- ALBA: Adaptive Load-Balancing Algorithm
- Cross-layer protocol
    - MAC (the nodes follows 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 = Queue Priority Index

GPI = Geographic Priority Index

Queue level

$$QPI = \lceil (Q + N_B) / M \rceil - 1$$

Requested length of the burst

Average length of a burst the relay expects to transmit correctly

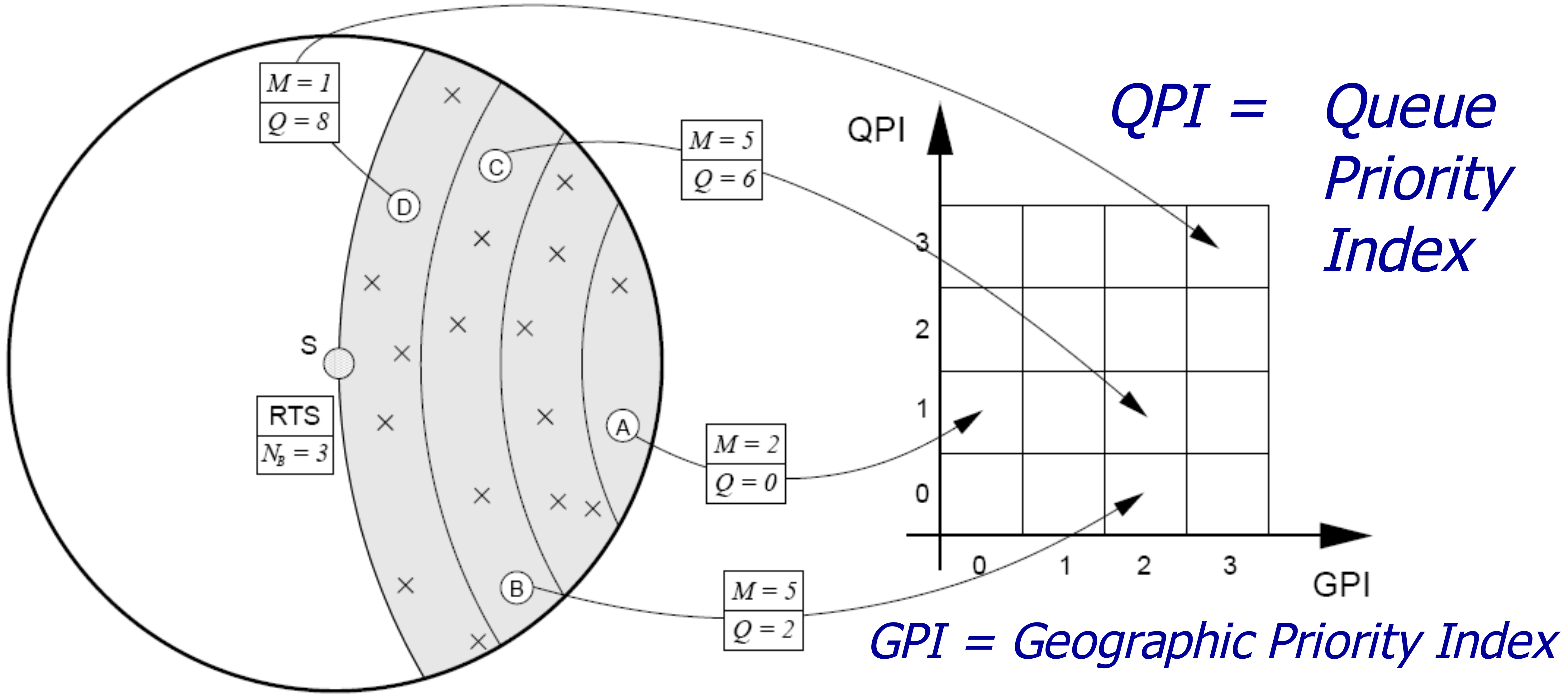
ALBA (3)

- 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)

ALBA: example



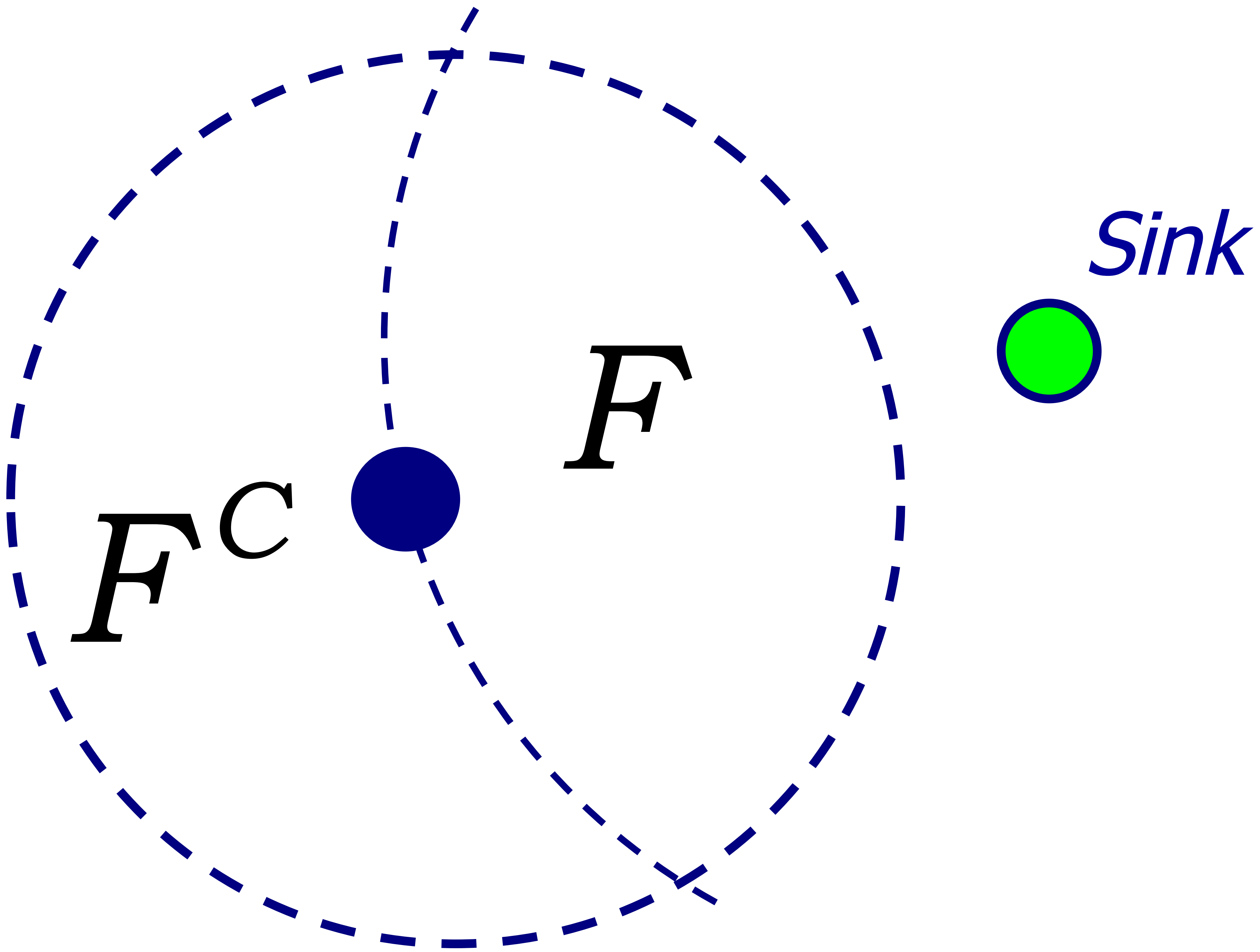
1) Node A is nearer to the sink (GPI=1) but has a low QPI (M=2); node B, is farther but is more reliable (M); B has a better QPI than A
2) If Node B is asleep when the RTS is sent, node A is elected as forwarder

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

ALBA-R: Rainbow (2)

- 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!

6LoWPAN: how does it work?

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 Identificator* 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.