# RPL Routing Metrics and Constraints

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# RPL
# Routing Metrics und Constraints

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The general task of the **RPL** (IPv6 Routing Protocol for Low-Power and Lossy Networks) is to set up an optimal **DODAG** (Destination Oriented Directed Acyclic Graph) in a **LLN** (Low Power and Lossy Network) and then, if necessary, to adapt it to new situations in the LLN. To meet this challenge, different **Routing Metrics** must be used and different constraints taken into account and met. As a result, the established DODAG is the "best" that is optimal in terms of the **Objective Function** and meets all the **Constraints** [1], [4].

## Types of routing metrics

It should be emphasized that in the case of RPL, all parameters can be considered as **Metrics** that can serve as a measure of the quality of links or nodes. A distinction is made between **Link-based Metrics** and **Node-based Metrics**. Fig. 1 shows a list of those Metrics that have already been tested and found to be particularly suitable for use in RPL.

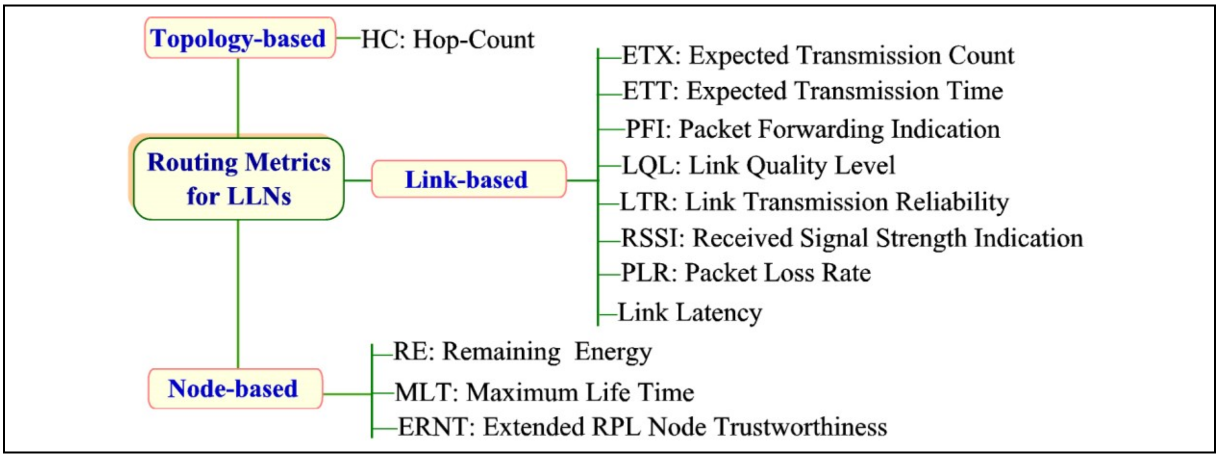


**Fig. 1**: Relevant routing metrics (a selection)

### Node-based Metrics

Node-based metrics are mainly related to the energy state of nodes. There are metrics that support security in IoT. The metric **ERNT** (Extended RPL Node Trustworthiness) mentioned in Fig. 1 is an example of this [5].

It should be noted that the Topology-based Metric HC (Hop Count) is comparable to the metrics of routing protocols in the Internet. For the metric HC all compounds have the same metric value - namely the value 1.

### Link-based Metrics

The Link-based Metrics **ETX** (Expected Transmission Count) and **ETT** (Expected Transmission Time) shown in Fig. 1 represent **Multidimensional Metrics**, in the sense that they enable the simultaneous consideration of various qualitative factors. These factors could be considered as **Unidimensional Metrics**, e.g. Packet Loss Rate, Link Transmission Reliability and Link Latency.

### ETX

The Link-based Metric ETX (see Figure 8364b in [1] or in [4]), which represents the statistically estimated average number of delivery attempts needed to successfully deliver a packet over the link, is a **Multidimensional Link-based Metric**. For example, it takes into account the quality parameters LTR (Link Transmission Reliability) and PRL (Packet Loss Rate). This can be justified as follows:

if {(LTR ⇨ max) and (PLR ⇨ min)} then {ETX ⇨ min}

Ideally, the LTR value would be high and the PLR value would be low. Consequently, ETX = 1. Statistically, this would mean that only one attempt would be needed to successfully transmit a packet via this link and thus no repeated transmission would be required.

> **Note:** The LTR metric of a link depends on the **Remaining Energy** (**RE**) of the linked nodes, that is, their **RE-based Metrics**. The decreasing RE values lead to link quality degradation such that the LTR values fall.

## Metrics und Constraints

It should be noted that some qualitative parameters such as **Link Reliability** or **Remaining Node Energy** can serve as Metrics, that is, as a kind of Objective Function parameter, and as Constraints that must be considered when determining routes. This is explained in more detail by the following examples.

**Example 1: Link Reliability as a Constraint**, **Metric of the route is additive**
It is to determine a route on which the quality of links determine the Metrics ETX. However, the route may only pass through links that guarantee a certain level of Reliability, so the Reliability of individual links must not be less than x (for example, x = 0.9). The route with the minimum **Rank** should serve as the optimal route (see Fig. 8363 in [1] or in [4]). In this case, the parameter **Link Reliability** acts as a Constraint and not as a Metric. Thus, since the Metric of the route is calculated by adding the metrics of individual links on the route, the metric of the route is additive.

**Beispiel 2: Link Reliability as a Metric**, **Metric of the route is multiplicative**
It is a route to determine where the quality of links determines their reliability as a metric. Since the metric of the route in this case is calculated by multiplying metrics of individual links on the route, the metric of the route is multiplicative.

The information about whether the metric of a route is additive or multiplicative, or whether the best route results in minimizing or maximizing its metric, must be entered in the message **DIO** (DODAG Information Object) when constructing or reconstructing a DODAG. How this can be done will be explained now.

## Specification of Routing Metric/Constraint Types

The use of different types of metrics as well as constraints require appropriate information for their unique interpretation at the receiving site. This information is transmitted in the **Metric Container** as part of the DIO [1], [2]. The Metric Container is used to transport a so-called **Routing Metric/Constraint Object**, referred to in short as **Routing M/C Object**. As its name suggests, such an object can contain either a **Routing Metric** or a **Routing Constraint**.

### Routing M/C Object

Each RPL message DIO contains a Metric Container with a **Routing M/C Object**. The content of the Object, whether it is a **Metric** or **Constraint**, is marked with **Flags C**, **O**, **R**, and **A** in the Metric Container. Fig. 2 illustrates the meaning of these **Flags** and shows how to use these Flags to specify which metric type or constraint type the Routing M/C Object contains and how to interpret them.

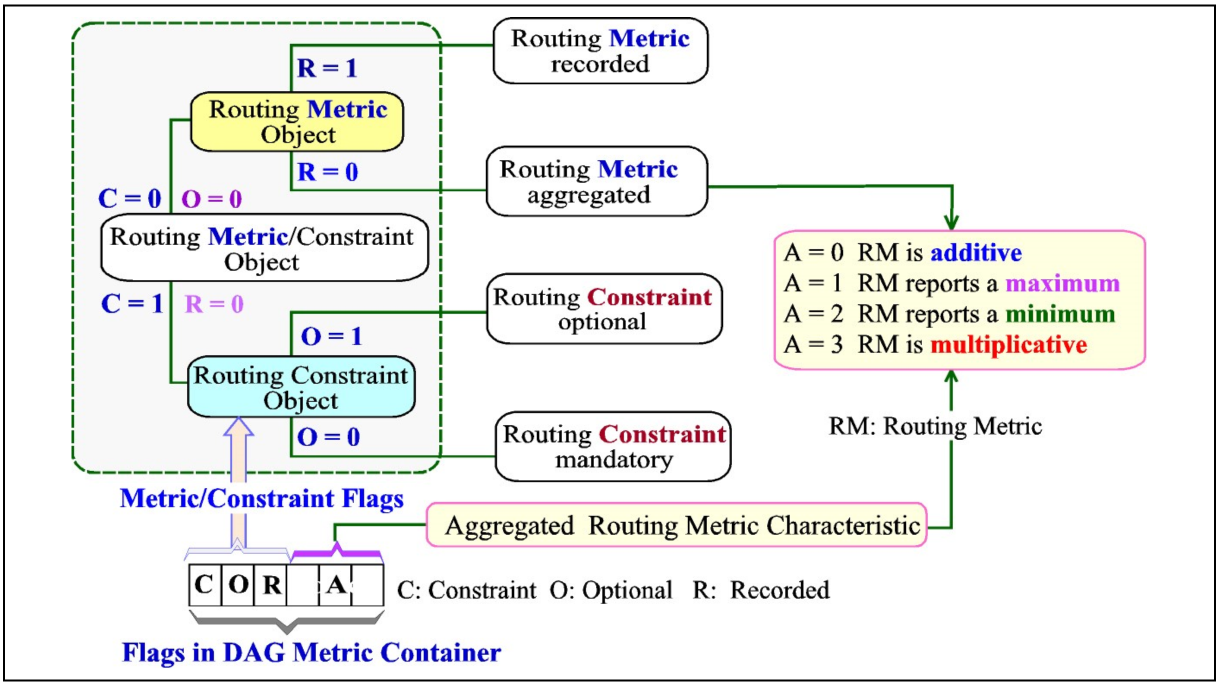


**Fig. 2**: Specification of the transported Routing Metric/Constraint types in the DAG Metric Container
DAG: Directed Acyclic Graph

As can be seen in Fig. 2, **Flag C** is used first to mark whether the Routing M/C Object transported in the Metric Container represents a **Routing Object** (C = 0) or a **Constraint Object** (C = 1). Thereafter, additional features of this object are given, in the following manner:

- If the M/C Object is a Routing Object (C = 0), then the **Flag R** indicates whether this metric should be considered as an **Aggregated Metric** (R = 0) or a **Recorded Metric** (R = 1).
- If the M/C Object is a **Constraint Object**, the **Flag O** indicates whether this Constraint should be considered mandatory (O = 0), that is, binding, or optional (O = 1).

Fig. 2 also indicates the importance of the three-bit **Indicator A**. It identifies (currently only) four types of path metrics. In particular, the A values 0 and 3 are to be emphasized:

- **A = 0** indicates that the Routing Metric is an **Additive Metric** and its value (e.g., Rank, Latency, Cost) represents the sum of the metrics values of each link in the route.
- **A = 3** points out that the Routing Metric is a **Multiplicative Metric** and its quality (e.g. **Reliability**) is calculated by multiplying the metrics of each link in the route.

## Recorded Metric und Aggregated Metric

The quality of routes can be defined and assessed differently. For their clear interpretation at the place of receipt, additional information must be entered in the RPL Message DIO. Here, the terms "Recorded Metric" and "Aggregated Metric" are used with the meaning described in Fig. 3.

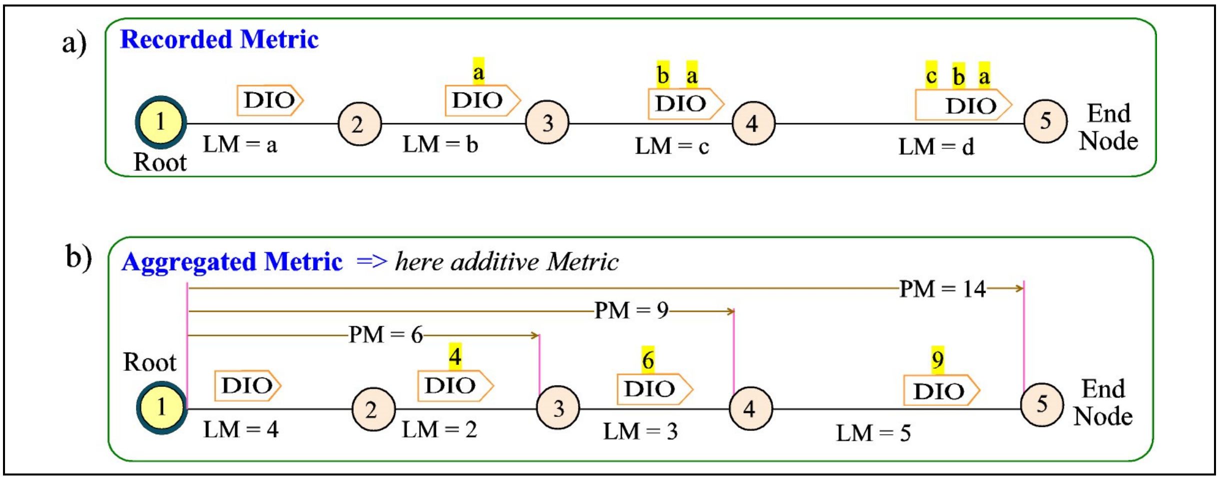


**Fig. 3**: Meaning of a) Recorded Metric and b) Aggregated Metric
DIO: DODAG Information Object
LM: Link Metric, Metric (Quality) of the links
PM: Path Metric, Metric (Quality) of the route

## Recorded Metric

As can be seen from Fig. 3a, the term **Recorded Metrics** refers to those metrics along a route that are recorded/registered on the way. The metric values of individual links on the way are collected and sent to an end node in the Message DIO. If a link along the route determines the quality of the entire route, the end node in Fig. 3a can be calculated, for example:

$\xi = \min\{a, b, c, d\}$

If this route is to be considered as an optimal route, on which the **longest data packets** can be transmitted without errors, **the route quality estimation** can take place according to the value $\xi$. In this case, the metrics of links represent their allowable packet lengths. The link with the shortest data packet length determines the quality of the route.

If one were to search for the route with the longest expected lifetime (Route Lifetime), then the node on the route with the lowest expected lifetime - Maximum Life Time (MLT) of node (Fig. 1) - determines the lifetime of the whole route. In this case, **the route quality estimation** can take place too according to the value $\xi$.

## Aggregated Metric

As shown in Fig. 3b, **Aggregated Metrics** – in contrast to Recorded Metrics – are already determined on the way. An Aggregated Metric can be **additive** or **multiplicative**. If the metrics of individual links are added along the route, e.g. when calculating Rank Values, this is an **Additive Metric**. If the metrics of individual links on the route are multiplied, such as in the calculation of the **Reliability** or **Availability** of a route, then the **metric of the route is multiplicative**.

## Supplementary Literature

[1] Badach, Anatol: RPL – IPv6 Routing Protocol for LLNs

[2] Badach, Anatol: RPL Message DIO

[3] Badach, Anatol: RPL messages and their structure

[4] Badach, Anatol: The Figures to the IoT Routing Protocol RPL

[5] Djedjig, Nabil; Tandjaoui, Djamel; Medjek, Faiza; Romdhani, Imed: New Trust Metric for the RPL Routing Protocol, 8th International Conference on Information and Communication Systems, Apr. 2017; DOI: 10.1109/IACS.2017.7921993