Energy-based routing metric for RPL

Patrick Olivier Kamgueu, Emmanuel Nataf, Thomas Djotio Ndié, Olivier Festor

Energy-based routing metric for RPL

Patrick O. Kamgueu, Emmanuel Nataf, Thomas Djotio, Olivier Festor

ISRN INRIA/RR--8208--FR+ENG

ISSN 0249-6399

RESEARCH REPORT
N° 8208
June 2012
Project-Team Madynes

Energy-based routing metric for RPL

Patrick O. Kamgueu*, Emmanuel Nataf†, Thomas Djotio*,
Olivier Festor†

Project-Team Madynes

Research Report n° 8208 — June 2012 — 14 pages

Abstract: Saving power while ensuring acceptable service levels is a major concern in wireless sensor networks, since nodes are usually deployed and not replaced in case of breakdown. Several efforts have recently led to the standardization of a routing protocol for low power and lossy network. The standard provides various metrics, which can be used to guide the routing. Most protocol implementations use expected transmission count as the routing metric, thus focus on the link reliability. To our knowledge, there is no protocol implementation that uses the nodes remaining energy for next hop selection. This document discusses about the usage of the latter as the routing metric for RPL, the new standard for routing for Low power and Lossy Network (LLN). We design an objective function for that metric and compared experiments result with the most popular expected transmission count scheme.

Key-words: routing, energy efficiency, RPL, Wireless Sensor Network.

* LIRIMA - Univeristy of Yaounde
† INRIA - Madynes Team

RESEARCH CENTRE
NANCY – GRAND EST

615 rue du Jardin Botanique
CS20101
54603 Villers-lès-Nancy Cedex

Métrique de routage RPL basée sur l'énergie

Résumé : La conservation énergétique, tout en assurant un niveau de service convenable est un soucis majeur dans les réseaux de capteurs sans fil, du fait que les nœuds sont généralement déployés et ne sont pas remplacés en cas de défaillance. Plusieurs efforts ont récemment conduit à la standardisation d'un protocole de routage pour les réseaux basses consommation avec perte. Le standard prévoit plusieurs critères pouvant être utilisés comme métrique de routage. La plupart des implémentations du protocole fait usage du taux de transmission avec succès (ETX) comme métrique, mettant ainsi l'accent sur la fiabilité des liens. A notre connaissance, il n'existe pas d'implémentation du standard qui prennent en compte l'énergie résiduelle des nœuds dans le processus de sélection du prochain saut. Dans ce rapport nous présentons l'utilisation de cette dernière comme métrique de routage pour le protocole RPL, nouveau standard de routage pour les réseaux de capteurs sans fil. Nous concevons une fonction objective pour cette métrique et comparons les résultats des expériences réalisées avec l'ETX.

Mots-clés : routage, efficacité en energie, RPL, Réseau de capteurs sans fil.

1 Introduction

Wireless Sensor Network (WSN) consist of up to hundreds or thousands of nodes scattered in an environment of interest, where nodes and their interconnect are constrained. Usually, each node sense its vicinity and forward measured parameters at a central point: the sink, through its neighbour via multi-hop radio communication. Nodes discover their neighbours, self-organize to build a topology and route sensed data. To deals with challenge presented by LLN, IETF Roll Working Group have recently published sevral standards related to RPL [21] [20] [19] [7].

RPL organizes networks as one or more Directly Acyclic Graph (DAG), each one rooted at a single point: the DAG root. Topology construction begins at this point, which periodically sends Destination Oriented DAG Information Object (DIO) via link local multicast. DIO carries necessary informations to build the topology, including root unique identifier, routing metrics, originating router's depth also called rank, and other network parameters. Nodes in the vicinity receiving DIOs, join DAG by selecting their parents (one or more) as next hop upwards to the sink. Parent selection process is governed by an Objective Function (OF), which uses routing metrics to select node's preferred parent among neighbours. Once node has made preferred parent selection, it determines its relative position to the DAG root based on the latter's rank, then node can originate its proper DIO messages. Different criteria also called routing metrics [20] are defined to capture link or node characteristics on the path for parent selection. They could be node attribute: hop count, node residual energy, or link attribute : throughput, latency, link quality level or expected transmission count (ETX). The latter is widely used in wireless sensor networks [2], moreover there are several RPL ETX-based implementations and IETF Roll Working Group has a long experience of routing [10] with this metric. The hop count and ETX are the only metrics for which standards related to their usage in RPL are published [19] [7]. Standards do not state how the other link/node attributes are transformed into path cost, nor how these costs are translated into DAG rank.

In this paper, using an online real time battery level estimation model, we design an OF for RPL that used node remaining energy as metric. The proposed OF is compared against the popular that rely on ETX.

The remainder of the document is organised as follows. In the next section we describe energy-based OF characteristics in terms of node battery level estimation, path cost and node rank computation. Section 3 presents protocols requirements and sufficient conditions for the routing metric to ensure proper operations, followed by some related work on energy aware routing in section 4. Implementation parameters, simulations and results are discussed in section 5. Section 6 concludes our work and discusses future directions.

2 Energy-based Objective Function

2.1 Path cost computation

The path cost or weight is a scalar value representing link or node characteristics along end-to-end path, for which the latter expresses some quality level. The calculation of this value depends on metric chosen by the network operator and must be the same on all nodes. Several choices are possible but they are not all reasonable. For example, following ETX approach, the path cost is computed as a sum of expected reliability on traversed links. For energy-based metric, we compute path cost as the minimum node energy level, that in our opinion, better captures the energy-based path weight than the sum of all nodes' energy along the path. According to the selected metric, optimal path from a given node is the one that maximizes or minimizes the path weight to the sink. After receiving a DIO from a neighbour, any non-root nodes computes the path cost through this neighbour:

- If routing metric is a node attribute, the path cost through that neighbour is the one indicated in the metric container option of the sender's DIO.
- Instead, if it is a link attribute, the path cost through that neighbour is computed from link metric on the interface to reach this neighbour and the path cost in the sender's DIO.

After a node has calculated path cost for all its neighbours and chose best parent in regard of the relation order for the selected metric, node updates its metric container (by computing it path through that parent) and starts to send its own DIOs.

2.2 Node' battery level estimation

To predict the lifetime of the node, we use a well-known battery model found in [16]. It uses the current consumption during each node state and its duration to estimate the battery remaining energy. The model is very accurate and cannot be implemented on real sensor nodes due to its complex computations and the memory size requirements. Rahmé et *al.* [15] have approximated the latter by simple computations on low memory to fit into sensor nodes, while maintaining the original model accuracy. Based on these approximations, we implemented this model on real sensor nodes, with the possibility to predict their lifetime online. This work can be found in a separate document [13]. Following RPL metrics recommendations [20], node residual energy is estimated on a scale of 255 (full) to 0 (empty). A key asset of the used model is that it take into account not only the *rate capacity*, but also the *recovery effect* that occurs during idle time. Note that this state may represent more than 90% of the node lifetime.

2.3 Energy based Path cost

We define the path cost PW_i from a node i to the sink as the minimum value between the preferred parent path cost and its own energy. The sink node set the value as MAX_{energy}. A node selects the neighbour that advertises the greatest path cost value as parent. More formally:

$$PW_i = \min[\max_{j \in N_i}(PW_j), E_i] \tag{1}$$

Where N_i is the set of node i's neighbours toward the sink, and E_i represents the energy of node i. For a given path, this value is also the same as the minimum node's energy level encountered on that path, since this energy is critical for the route lifetime.

Network topology shown in figure 1 depicts the proposed energy-based path cost. Node 1 is the sink and is main powered, other nodes at a given time are supposed to have residual energy as shown. To describe the topological structure of the network, we consider node 6 that selects 3 as next hop. Dashed lines and arrows represent neighbour reachability. Node 6 receives neighbour's 3, 4, 5 and 8 DIOs, containing respectively values $PW_3 = 220$, $PW_4 = 215$, $PW_5 = 217$, and $PW_8 = 240$. So 6 selects 3 which indicate higher path cost, as best parent. Following the procedure described above, similarly other nodes select their next hop to the sink.
At another time, assume that node 3, the most solicited waste more energy compared to others, so that it decreases by 20 units, while 5 units for others. Figure 2 illustrates how network topology reacts according to the new path cost computed by each nodes:

1. Node 3 is no longer the best parent to the sink for 6, which finds a more interesting path through 4 ($PW_3 = 200$ while $PW_4 = 210$).
2. Similarly, node 5 follows 6 that offers a better path than 3 ($PW_3 = 200$ while $PW_6 = 205$).

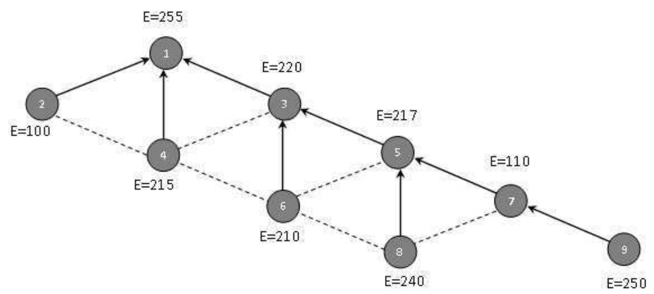


Figure 1: Example of energy based path cost computation

2.4 Energy based DAG Rank

To avoid cycle in the network, every node uses a scalar values : the rank, to record its relative position to other nodes with regard to DODAG root. RPL does not states how rank values are computed at each nodes, but the values must implement generic properties regardless the objective function in uses. The rank is not the path cost, although its value is derived from the latter. Rank value must monotonically decrease as we move upwards to the sink, but it does not necessarily change as fast as some link or node metrics would. For the latter reason rank values is thought as a fixed-point number where the position of the radix point between the integer part and the fractional part is determined by the `MinHopRankIncrease` parameter (provided by the DODAG root). When rank is compared for parent relationships or loop detection purpose only the integer part is used, but OF computes entire fixed-point value (16-bit). Once a node (say N) has chosen its preferred parent (P), node computes its own rank from preferred parent's rank as defined in (2) where $step = MAX_{energy} - Node_{energy}$.

$$\begin{array}{ll} Rank(N) = Rank(P) + Rank_{increase} & \\ \text{where} \qquad Rank_{increase} = step + MinHopRankIncrease & \end{array} \tag{2}$$

This formula ensures the monotonic property of the rank which increases by at least one point (`MinHopRankIncrease`) between node and its preferred parent, when child node has a full battery level. The increment is even greater as node consumes its battery, because of penalty of step which feeds the fractional part of fix-point rank value. By cumulative effect of penalties in the node's parentage, node's rank can grow to more than one point (see Table 1 - rank increase between node 5 and 7). Figure 2 illustrates how rank is derived from path cost, and table 1 emphasizes on rank computation on path 1-4-6-5-7-9. Root rank is set to the same value as `MinHopRankIncrease` (256 in this example).

Node ID	Fix-point value	Fractional Part	Interger Rank value
1	256	0	1
4	557	45	2
6	863	95	3
5	1162	138	4
7	1568	32	6
9	1834	42	7

Table 1: Detailed Rank Calculation

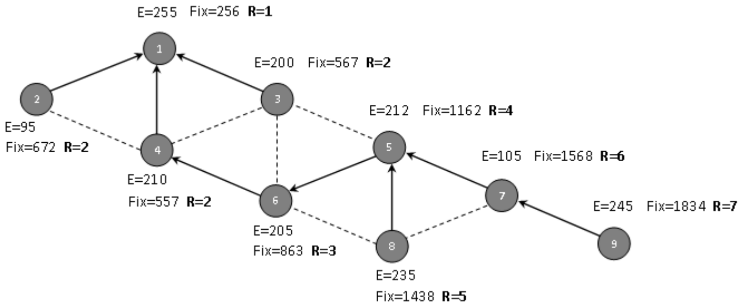


Figure 2: Rank calculation for energy-based OF

Following this scenario, although node 7 and 8 have same preferred parent (5), 8's relative distance to DAG root is better than 7's relative distance.

3 Protocol requirements and routing metric properties

The diversity of wireless sensor network requirements motivates the design of various routing metrics, to capture different aspects of wireless communication. For that reason, Yang et *al.* [22], provide a systematic analysis of the relationship between routing metrics and routing protocols. Taking into account the theoretical algebra framework of Sobrinho [18], they identify the basic properties that a routing metric must have in order to properly operate with different proactive or reactive routing protocols in wireless networks. Metrics that do not meet these requirements may lead to routing loops and suboptimal paths. The following requirements ensure proper operations for routing protocol:

- **consistency**: routing protocol is said consistent if packet forwarding decisions for all nodes along a given path is consistent with each node in that path. In this sense, if node n_1 decides that the traffic to n_k should follow the path $p(n_1, n_k) = \langle n_1, n_2, \cdots, n_k \rangle$, other nodes along this path should make the same decision, *i.e* n_2 should choose path $p(n_2, n_k) = \langle n_2, n_3, \cdots, n_k \rangle$ to forward traffic to n_k, and the same for $n_3, \cdots, n_{k-1}$.

- **optimality**: It is a generic requirement for routing protocol, such as it always forward packets along the lightest path (in regard of weight of metric) between every pair of nodes. Lack of this requirement may be caused by inconsistency routing.

- **loop-freeness**: it is the most relevant requirement for a routing protocol, routing loops occurs when a packet is forwarded between a set of nodes without ever reach its final destination.

As established by [18], necessary and sufficient conditions for a routing metric to achieve these requirements are to satisfy properties of isotonicity and monotonicity. To highlight this, a routing metric can be represented as an algebra on top of a quadruplet $(\Sigma, \oplus, w, \preceq)$, where Σ is the set of all path, $\oplus$ the path concatenation operation, w a function that maps a path into a cost and $\preceq$ is an order relation.

Isotonicity

The isotonic property mean that the order relation between two paths is preserved if they are both prefixed or appended by a common third path. More formally, the algebraic structure $(\Sigma, \oplus, w, \preceq)$ is said isotonic if $\forall a, b, c \in \Sigma$, $w(a) \preceq w(b)$ implies both $w(c \oplus a) \preceq w(c \oplus b)$ and $w(a \oplus c) \preceq w(b \oplus c)$.

Monotonicity

The isotonic property mean that the path cost will not decrease when prefixed or appended by another path. More formally, $(\Sigma, \oplus, w, \preceq)$ is said monotonic if $w(a) \preceq w(c \oplus a)$ and $w(a) \preceq w(a \oplus c)$ holds $\forall a, c \in \Sigma$.

As shown below, the proposed minimum energy-cost metric for RPL is proved both isotonic and monotonic. Thus in accordance with [22], we conclude that the routing metric satisfy consistency, optimality and loop-freeness requirements. The algebraic structure build for the proposed metric is $(\Sigma, \oplus, \min, \geq)$, where $min(p)$ is the minimum energy-based cost along the path p and the order relation for that routing metric is $\geq$. Since $\oplus$, the path concatenation operator is commutative for min function, we can limit the demonstration only to the *left*-isotonicity and *left*-monotonicity ($i.e$ for prefixed paths) of the algebraic structure. Indeed:
Isotonicity: Let us consider two given paths a and b so that $min(a) \geq min(b)$, we want to show that this implies $min(c \oplus a) \geq min(c \oplus b)$. For the former inequality three cases could occur for a given prefixed c path.

1. $min(c) \geq min(a)$: we have
   $min(c \oplus a) = min(a)$ and $min(c \oplus b) = min(b) \Longrightarrow min(c \oplus a) \geq min(c \oplus b)$.

2. $min(a) \geq min(c) \geq min(b)$: we have
   $min(c \oplus a) = min(c)$ and $min(c \oplus b) = min(b) \Longrightarrow min(c \oplus a) \geq min(c \oplus b)$.

3. $min(b) \geq min(c)$: we have
   $min(c \oplus a) = min(c \oplus b) = min(c) \Longrightarrow min(c \oplus a) \geq min(c \oplus b)$. ■

Monotonicity: Now, we seek to show that $min(a) \geq min(c \oplus a)$. $\forall a, c \in \Sigma$. Two cases could occur:

1. $min(a) \geq min(c)$: we have
   $min(c \oplus a) = min(c) \Longrightarrow min(a) \geq min(c \oplus a)$.

2. $min(c) \geq min(a)$: we have
   $min(c \oplus a) = min(a) \Longrightarrow min(a) \geq min(c \oplus a)$. ■

4 Related Wok on Energy-aware Routing

One major goal in Wireless Sensor Network is conserving the sensor nodes energy and thus maximizing the network lifetime. Several protocol have been proposed in the literature taking into account various parameters to improve the energy efficiency in the network. Some work have focussed on energy efficient techniques including data aggregation, network clustering [9], data centric or event driven [11]. Among the techniques used to maximize the network lifetime, energy aware routing protocol appears to be suitable for multi-hop wireless sensor networks, since they explicitly take into account node residual energy for route establishment. As energy is depleted, the network may be required to reduce the quality of sent data in order to reduce energy dissipation.

The Energy Efficient Shortest Path protocol [17] follows shortest path algorithm by combining distance (hop count) and node residual energy as cost . This combination uses the energy metric at the denominator of the distance parameter.

Similarly, authors in [12] propose an algorithm which considers both energy and delay metric to find an optimal path with minimum energy consumption and minimum end to end delay for real time traffic in wireless sensor networks. This cost is computed as a linear combination of the transmission delay and node's energy on the path.

Chiang and *al* proposed Minimum Hop (MH) routing protocol [1] which organize routing topology based on nodes hop counts and battery power levels. For a given nodes, neighbours are classified into three categories: *parent*, *sibling* and *child node*, on the basis of their vicinity in hop count to the sink. A Parent node has always a hop count one less than the sending node, sibling node the same, whereas the child node is in the transmission range but having a hop count one more than the sending node. MH first try to reach sink by path through a parent node, which guarantee a minimum hop path. In case of more than one parent protocol uses parent with the highest energy level. If there is no parent node available, sending node forward data through the sibling node which has the highest energy.

MH uses a local (parent and sibling) energy view of the sender for the next hop selection, and does not always reflect the real energy distribution of nodes in the path. On contrary, authors in [6] proposed the path energy weight (PEW) protocol that improve MH by using an energy-weighted function to indicate how balanced is the energy distribution among all nodes along the path. With the same notation as the equation 1, the path cost is:

$$PW_i = 2^{(-\frac{W_{max}}{E_{max}}E_i + W_{max})} \min_{j \in P_i \cup S_i} (PW_j) \tag{3}$$

Where PW_j is the path with best energy weight function from the set of all parents (P_i) and siblings (S_i) nodes of the sensor i to the sink. W_{max} and E_{max} are experiments dependant parameters which bound PW values. To illustrate MH and PEW operations, we consider the

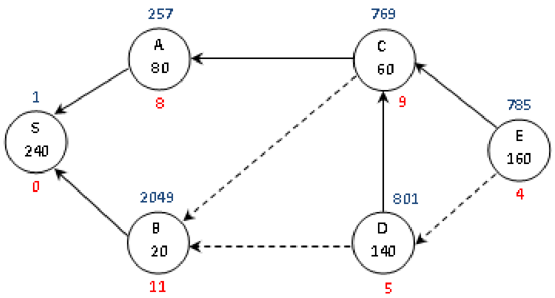


Figure 3: MH and PEW operations

network shown in the figure 3 (where energy level of each sensor is indicated below the node's ID); for which node E needs to send data to sink (S). Based on MH protocol, E selects among both parent nodes (C and D), the ones with the higher energy level: D in this case. E's data will be sent through path $E \to D \to B \to S$, leading node B to drain all its battery and some part of network could become disconnected. According to PEW, node E selects C as next hop based on path energy weight, where weighted energy function of each node (W_i) is indicated below node ID in red ($E_{max} = 240$ and $W_{max} = 12$), and path energy weight (PW_i) is indicate above in blue. Following this scenario, node E sends data through $E \to C \to A \to S$, and therefore PEW protocol more extend network lifetime than MH. Note that, on the one hand this path weight takes into account all nodes energy along the path, although greatly disadvantaging lower energy nodes. In our approach, only the lowest nodes constraint the path. On the other hand, the set of the potential next hop $P_i \cup S_i$ is only determined by hop count, whereas we use the rank notion to choose the next-hop among the neighbours, while avoiding loops.

Unlike previous protocols which attempt to find a minimum energy cost path, REAR (Reliable Energy Aware Routing) [8] provides an energy-sufficient path instead. The protocol is intended to establish a reliable transmission environment for data packet delivery with low energy cost. The algorithm proceed in four steps: (1) Path Discovery including Service Path Discovery (SPD) and Backup Path Discovery (BPD); (2) Energy Reservation including Service Path Reservation (SPR) and Backup Path Reservation (BPR); (3) Reliable Transmission (RT) and (4) Reserved Energy Release (RER).

When the sink receives an interest, it checks its routing table for a route to the target. If no route the source exits in the table, the sink floods a service-path request through the network until it reaches the source. After the source retrieves the route information from the first received request packet, it will unicast a corresponding service-path reservation request along the retrieves path towards the sink, indicating the amount of energy requested to reserve (E_{resv}). Every intermediate node on this path will mark part of its energy as reserved for this communication, and that one is no longer available for other communication. After end of this service path discovery and service path reservation, the sink will launch a backup path discovery to the same source. SPD and BPR are carried out in the same manner except that only the intermediate nodes which are not on the service-path, will relay messages to their neighbours. Therefore, a two completely disjoints paths are established and reserved between sink and source for reliability purpose and fast topology reconstruction. Reserved energy release is initiated when the path is broken. The path-reservation process is concerned with energy, different sources might reserve different quantity of energy for their path, depending on an estimation of the quantity of data from that source.

To facilitate the selection of path having high energy level nodes, REAR introduces delay when flooding network during route discovery. Each intermediate node does not broadcast the message to its neighbours upon reception, instead each node delays the message based on its available energy (which is the residual remaining energy excluding all reserved energy). Using this delay scheme, energy-weak nodes are kept out of the potential path, and time-shortest route are promoted. One major challenge with REAR is to determine the accurate value for E_{resv}, since reserved energy along the service and backup path can prevent some nodes to be selected for another Sink - Source route, even though the backup path is not used. Since the wireless sensor network environment is error-prone with a high packet loss rate, the delayed process during route discovery can lead to select less available energy-sufficient path, leading some nodes to depleted more quickly their energy. Moreover, REAR is an on demand, reactive routing protocol, it would not be appropriate for networks where nodes send data very frequently.

5 Simulations and results

5.1 Environment setup

Using Cooja simulator [14] we evaluated the performance of RPL with both, energy-based and expected transmission count metrics, on the tiny networked sensors operating system Contiki [4]. Experiments were carried out using a $300 \times 300m^2$ 2D-grid of 20 sensors network topology. The sink is located at the left upper corner. Each sensor node acts in $120m$ maximum transmission range, $140m$ interference range, and periodically sends data to sink using UDP as the transport layer with a Tx/Rx success ratio of 80%. The layer 2 medium access control is ContikiMAC [5] that provides power efficiency by the node keeping their radios turned off for roughly 99% of the time. All nodes have fully charged battery at the beginning of the simulations, with an initial power level set to $880mAh$. The hardware characteristics for the simulation computer is 3.2Ghz Dual Core Intel XEON processor board, with 8GiB Memory size, on Ubuntu 11.10 Operating System. Figure 4 presents a snapshot of the network and nodes layout, where the arrows indicate the selected next hop according to the routing metric. For example, concerning the node 7, the green area define its transmission range and the gray circle, the corresponding interference range. Below each circumscribed node is indicated the link quality with the selected node.

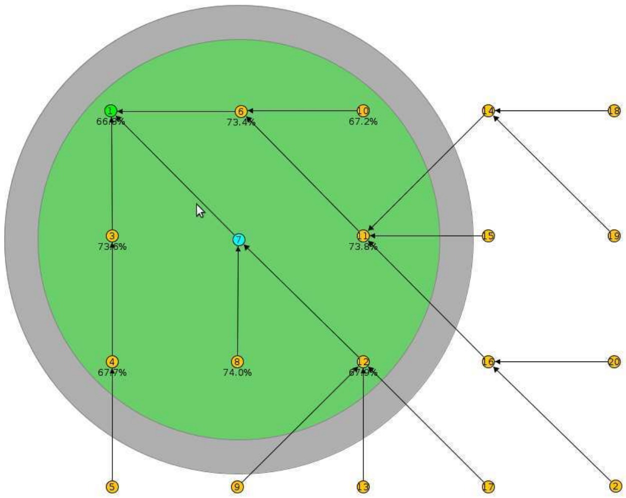


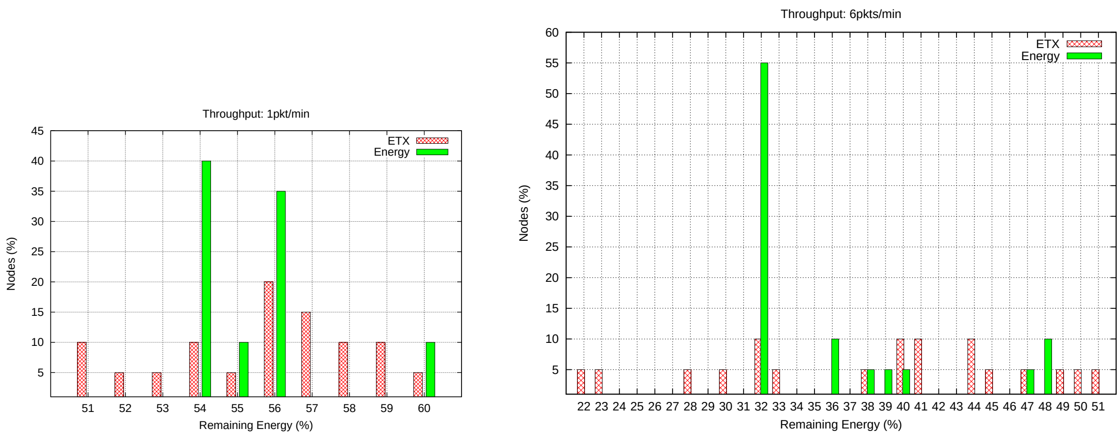
Figure 4: A snapshot of the simulated network

5.2 Results

Simulations were performed for one month network activities (corresponding to 13 real days on our simulation computer) to demonstrate the increase on network survivability without lack of accuracy. We define the network lifetime as the date on which the first node has completely exhausted its battery [3]. The energy aware RPL implementation was compared against the ETX implementation. For both, the sink collects data generated at various throughput expressed as the number of application packets per minute ($pkts/min$), each having 87 bytes of size. Then, we evaluate nodes energy depletion and packet delivery ratio for both scenarios, one at $1pkt/min$, the other at $6pkts/min$.

5.2.1 Remaining Power Distribution

Energy aware routing aims to use nodes with higher remaining power level, thus these nodes drain their battery more quickly and further become less attractive to relay data. The network should be reorganized to find more interesting nodes for routing and so on, thereby a balancing on all nodes battery levels should occur. This can be seen in figure 5 which presents the proportion of nodes in the network with the corresponding percentage of remaining energy at the end of the simulation. In figure 5a at $1pkt/min$, 85% of nodes have their power level between the range 54% to 56%, whereas the ETX-based routing spread the energy distribution unequally among the nodes. At a higher rate ($6pkts/min$) in figure 5b, this observation is much more pronounced, since the traffic flow is more important and nodes exhaust their battery much faster. At the same time, in both illustrations the ETX-based scheme presents much less-power nodes (around 20%) than the energy aware scheme, the latter delaying the first nodes that will completely exhaust their battery and the possibility to create network holes. This is an important point, because the



(a) (b)

Figure 5: Nodes Remaining Power Distribution

network integrity can be affected when some nodes are stopped. Figure 6 represents the battery variation for lowest power nodes at a throughput of $6pkts/min$ in both implementations, using these informations, we estimated by a linear regression when first nodes drain completely their energy. Computations indicate a network lifetime of 35 days for ETX-based RPL, while 40 days for energy aware scheme, thus the increase in network lifetime is around 14%.

5.2.2 Transmission Accuracy

We also evaluated the accuracy of routing to collect the application data. ETX-based routing promotes routes with higher packets delivery ratio, while energy aware routing don't care on that. It is therefore not surprising that the number of received packets with ETX is slightly greater than energy aware scheme as outlined by the figure 7, which depicts the total number of received packets from each node by the sink. The table 2 summarize all received packets at the

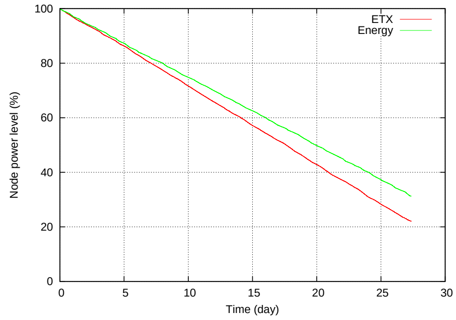


Figure 6: Power depletion for lowest nodes

sink, as well as all sent packets for both rates. Again, ETX-based routing delivery ratio is better than energy aware scheme, but this difference in only around 3%.

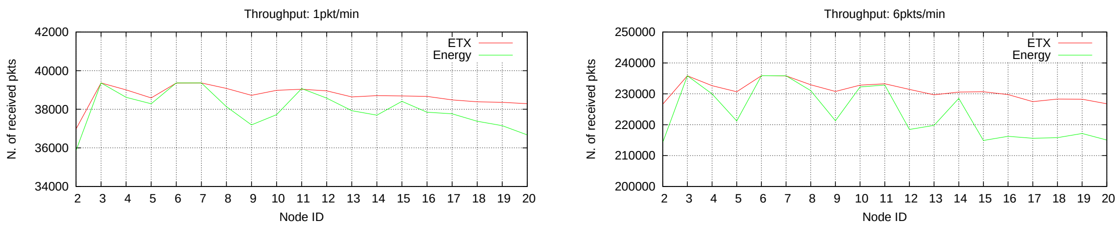


Figure 7: Received packet at the sink node

Throughput	Sent Pkt	Received (ETX)	Received (Energy)
6 pkts/min	4488635	4390282 (97.80%)	4251962 (94.72%)
1 pkt/min	748105	735680 (98.34%)	722394 (96.56%)

Table 2: Transmission Accuracy

6 Conclusion and future works

In this paper, we presented an instantiation and implementation of the routing protocol for low power and lossy network that uses the node's remaining energy as the main routing metric. The implementation makes use of a well-known battery theoretical model from which we estimate at runtime the node battery lifetime for routing. Experiments reveal that, compared to the popular RPL ETX-based scheme, the proposed implementation increase the network lifetime and distributes energy evenly among nodes without an appreciable lack of the transmission accuracy.

Our future works aims to combinate these both metrics (energy and ETX), in accordance with [23]. We expect to leverage the strengths of each, and obtain a better compromise. Furthermore we seek to provide additional decision criteria in order to better guide the routing decisions in WSN.

References

[1] S. Chiang, C. Huang, and K. Chang. A minimum hop routing protocol for home security systems using wsn. *IEEE Trans. on Cons. Elec.*, 53:1483 – 1489, Nov. 2007.

[2] D. S. Couto and D. Aguayo. A high-throughput path metric for multi-hop wireless routing. In *Proceedings of 9th ACM annual international conference on Mobile computing and networking*, pages 134 – 146, San Diego, USA, Sept. 2003.

[3] I. Dietrich and F. Dressler. On the lifetime of wsn. *ACM: Trans. on Sensor Networks*, 5, Feb. 2009.

[4] A. Dunkels. Contiki - a lightweight and flexible operating system for tiny networked sensors. In *Proceedings of the First IEEE Workshop on Embedded Networked Sensors (Emnets-I)*, pages 455 – 462, Tampa, USA, Nov. 2004.

[5] A. Dunkels. The contikimac radio duty cycling protocol. Technical Report ISBN 1100-3154, SICS, Dec. 2011.

[6] A. M. El-Semary and M. M. A. Azim. Path energy weight: A global energy-aware routing protocol for wireless sensor network. In *Proc. of IFIP WD*, Venice, Oct. 2010.

[7] O. Gnawali and P. Levis. The Minimum Rank with Hysteresis Objective Function. RFC 6719 (Proposed Standard), September 2012.

[8] H. Hassanein and J. Luo. Reliable energy aware routing in wireless sensor network. In *Proceedings of the Second IEEE Workshop on Dependability and Security in Sensor Networks and Systems (DSSNS)*, pages 54 – 64, Columbia, USA, Apr. 2006.

[9] W. Heizelmann, J. Kulik, and H. Balakrishman. Adaptative protocols for information dissemination in wireless sensor networks. In *Proceedings of the 5th Annual ACM/IEEE International Conference on Mobile Computing and Networking (MOBICOM)*, pages 174 – 185, Seattle, USA, Aug. 1999.

[10] J. Hui and D. Culler. Ip is dead, long live ip for wireless sensor networks. In *Proceedings of 6th ACM Conference on Embedded Networked Systems*, pages 15 – 28, Raleigh, USA, Nov. 2008.

[11] C. Intanagonwiwat, R. Govindan, and D. Estrin. Directed diffusion : A scalable and robust communication paradigm for sensor networks. In *Proceedings of the 6th Annual ACM/IEEE International Conference on Mobile Computing and Networking (MOBICOM)*, pages 56 – 67, Boston, USA, Aug. 2000.

[12] A. Mohajerzadeh and M. Yaghmaee. An efficient energy aware routing protocol for real time traffic in wsn. In *Proc. of ICUMT*, pages 1 – 9, St-P, Russia, Oct. 2009.

[13] E. Nataf and O. Festor. Online estimation of battery lifetime for wireless sensors network. In *Proc. of 2nd Sensornets*, Barcelona, Spain, Feb. 2013.

[14] F. Osterlind and A. Dunkels. Cross-level sensor network simulation with cooja. In *Proc. of 31st IEEE Conf. SenseApp*, pages 641 – 648, Tampa, Florida, 2006.

[15] J. Rahmé and N. Fourthy. Energy management for battery-powered embedded systems. In *Proc. of IEEE WCNC*, pages 277 – 324, Sydney, Apr. 2010.

[16] D. Rakhmatov and S. Vrudhula. Energy management for battery-powered embedded systems. *ACM trans. on Embed. Comput. Syst*, pages 277 – 324, Aug. 2003.

[17] K. S. Shivaprakasha and M. Kulkarni. Energy efficient shortest path routing protocol for wsn. In *Proc. of 3rd CICSyN*, pages 333 – 337, Bali, Indonesia, Jul. 2011.

[18] J. Sobrinho. Network routing with path vector protocols: Theory and applications. In *Proceedings of ACM SIGCOMM*, pages 49 – 60, Karsruhe, Germany, Aug. 2008.

[19] P. Thubert. Objective Function Zero for the Routing Protocol for Low-Power and Lossy Networks (RPL). RFC 6552 (Proposed Standard), March 2012.

[20] JP. Vasseur, M. Kim, K. Pister, N. Dejean, and D. Barthel. Routing Metrics Used for Path Calculation in Low-Power and Lossy Networks. RFC 6551 (Proposed Standard), March 2012.

[21] T. Winter, P. Thubert, A. Brandt, J. Hui, R. Kelsey, P. Levis, K. Pister, R. Struik, JP. Vasseur, and R. Alexander. RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks. RFC 6550 (Proposed Standard), March 2012.

[22] Y. Yang and J. Wang. Design guidelines for routing in wireless sensor network. In *Proceedings of 27th IEEE INFOCOM*, pages 1615 – 1623, Phoenix, USA, Apr. 2003.

[23] T. Zahariadis and P. Trakadas. Design guidelines for routing metrics composition in lln. IETF Work in progress, Nov. 2012.

RESEARCH CENTRE
NANCY – GRAND EST

615 rue du Jardin Botanique
CS20101
54603 Villers-lès-Nancy Cedex

Publisher
Inria
Domaine de Voluceau - Rocquencourt
BP 105 - 78153 Le Chesnay Cedex
inria.fr

ISSN 0249-6399