6-9 June, 2017
Geneva

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CICG

SEEOF: Smart Energy Efficient Objective Function

Adapting RPL Objective Function to enable an IPv6 Meshed Topology Solution for Battery Operated Smart Meters

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Outlines

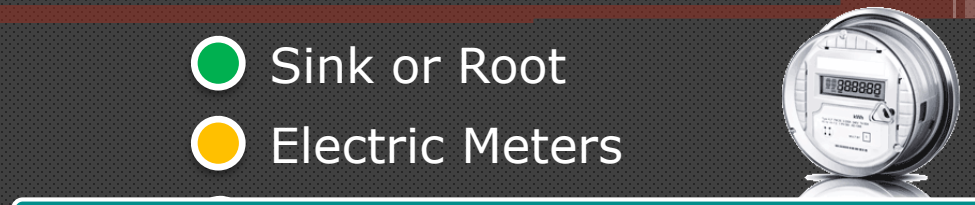
- Background
- SEEOF - Proposed Algorithm
- Simulations, Graphs and Results
- Conclusion and Future Work

Background

- Internet of Things (IoT)
- Smart Meters
  - Top IoT device among utility companies in the last several years
- Low Power and Lossy Networks(LLN)
- RPL (IPv6 Routing Protocol for LLNs)
  - Prounounced as "RIPPLE"
- **Electric Meters** + **Gas/Water Meters**

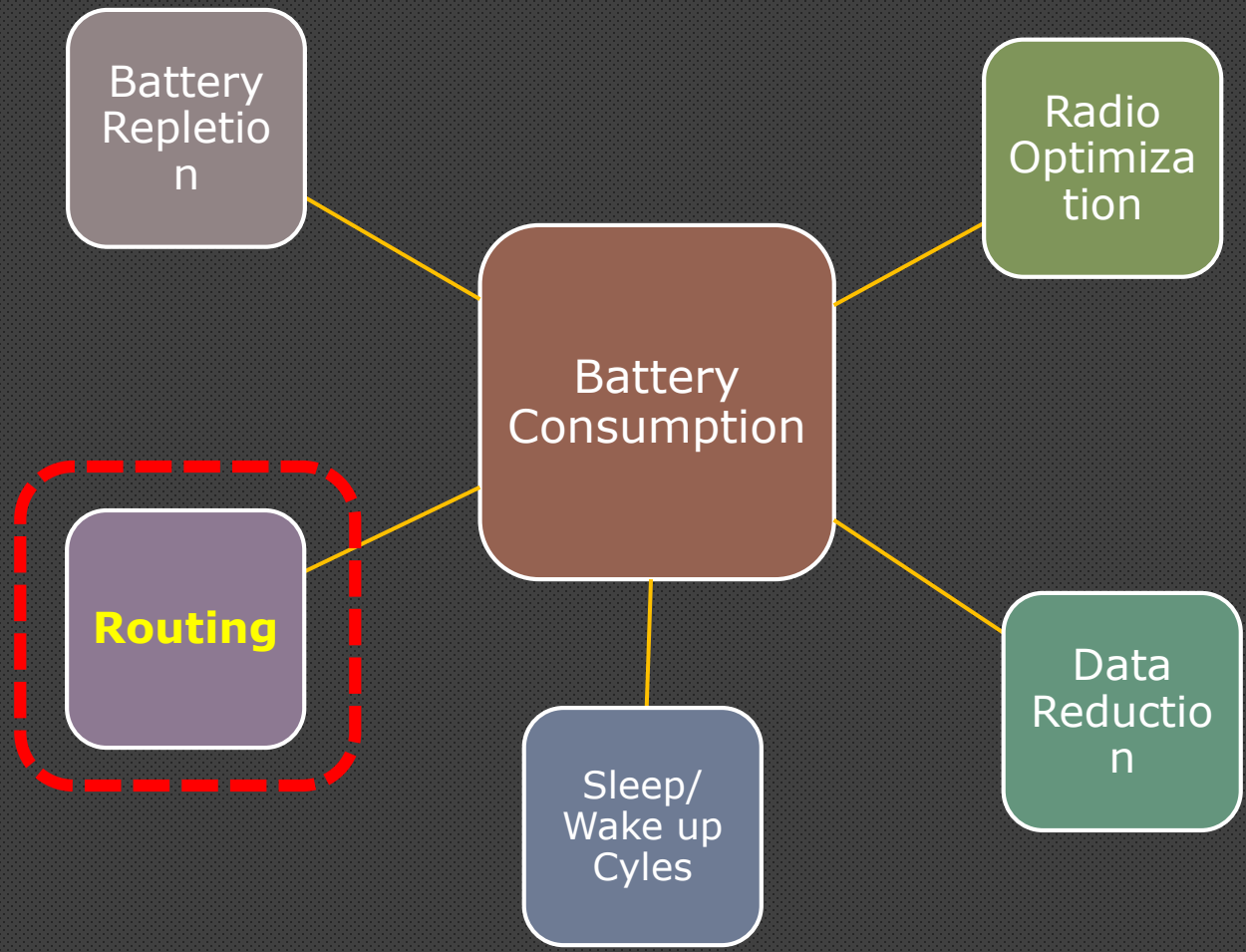
Mains line powered
(**MLPD**)

Battery powered
(**BPD**)



Background

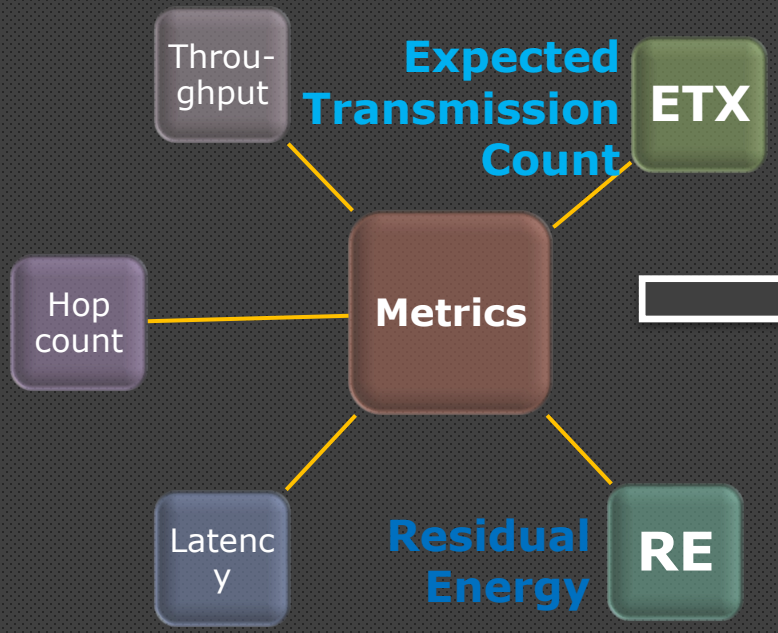
Node's energy
Vital resource

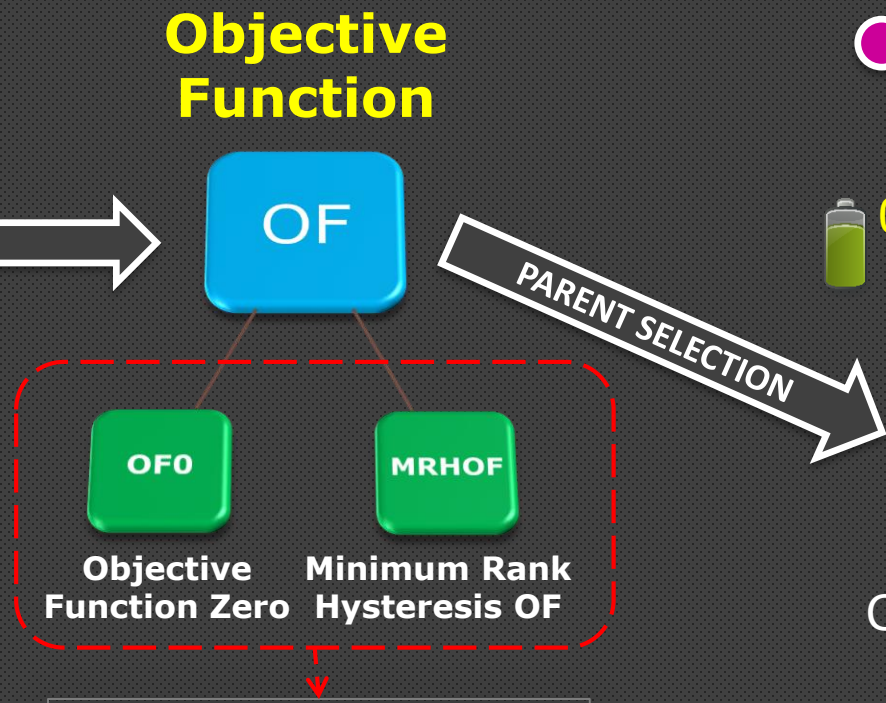


- Routing
  - Key Factor for Meshed network
  - Prominent responsibility to make a smart decision in selecting the optimal parent and
  - Construct the routes in a single or multi-hop manner

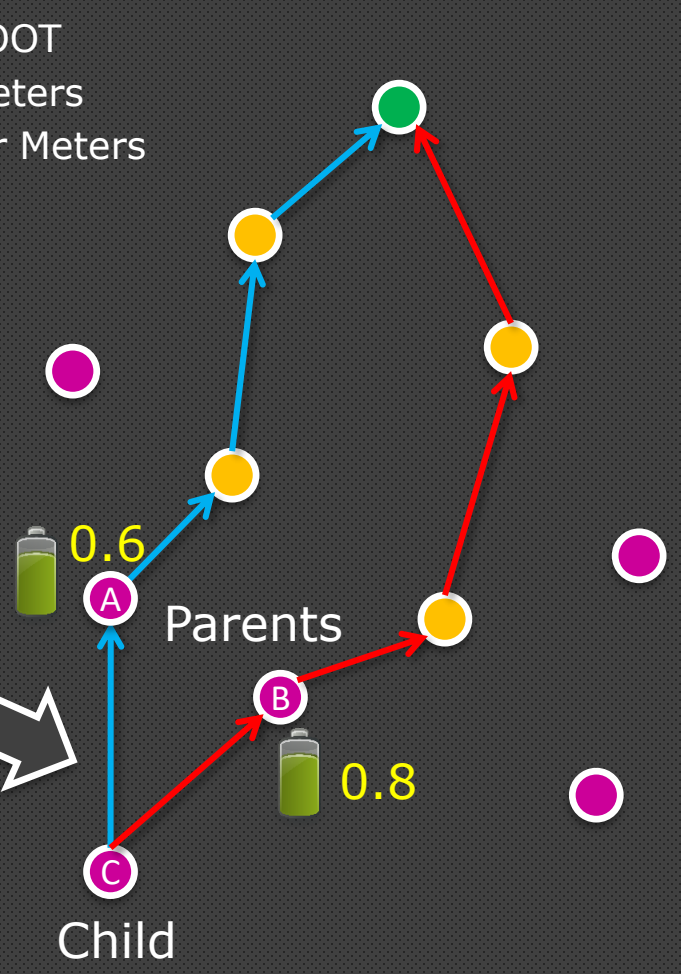
Background

- Parent Selection





Works on Single Metric only **PROBLEM!!**



- Only ETX : C → A
- Only RE : C → B

$$PathETX = \sum_{l \in P} linkETX$$

5.1 path ETX

6.5 path ETX

Goal

SEEOF

→ In compliance with the standard RPL

→ Consider the consumption limits of BPDs

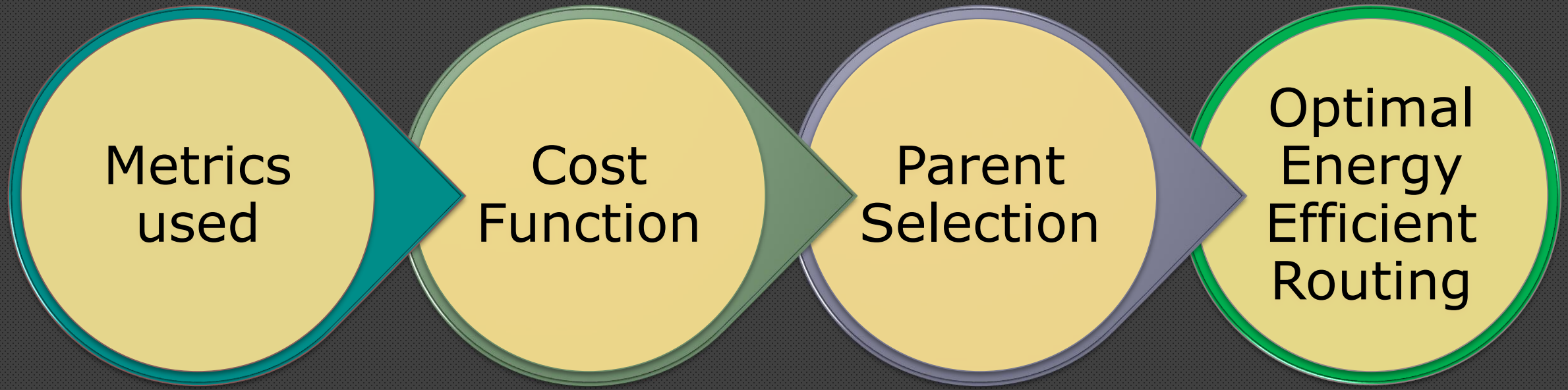
AIM

→ Balanced and Efficient Energy consumption

→Improve the Network Lifetime

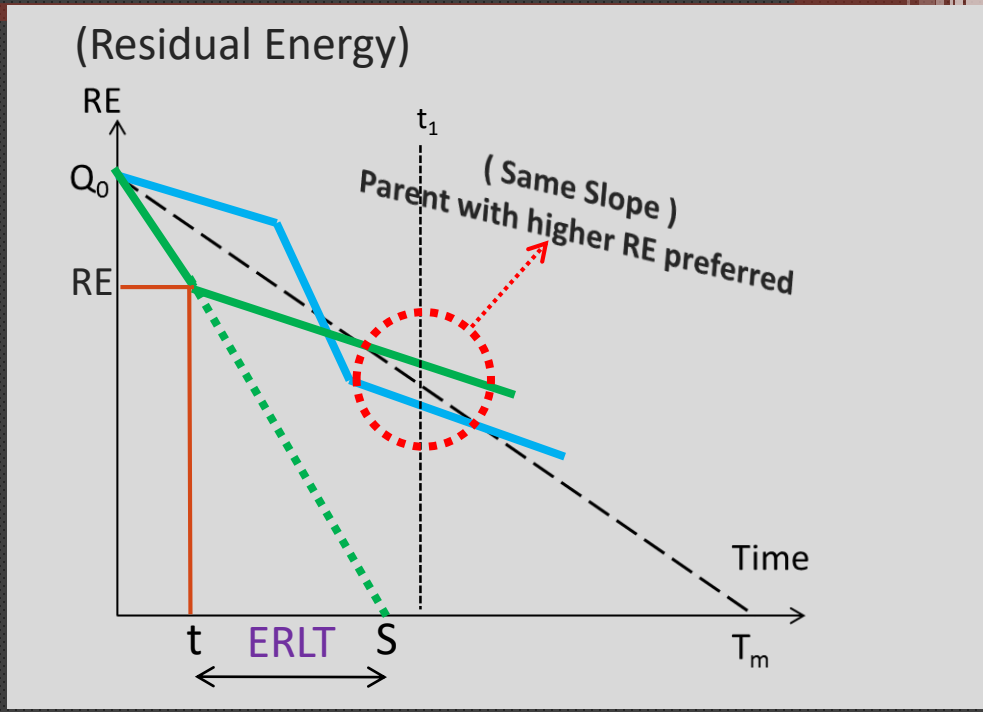
→ No or low compromise with the quality of service.

SEEOF

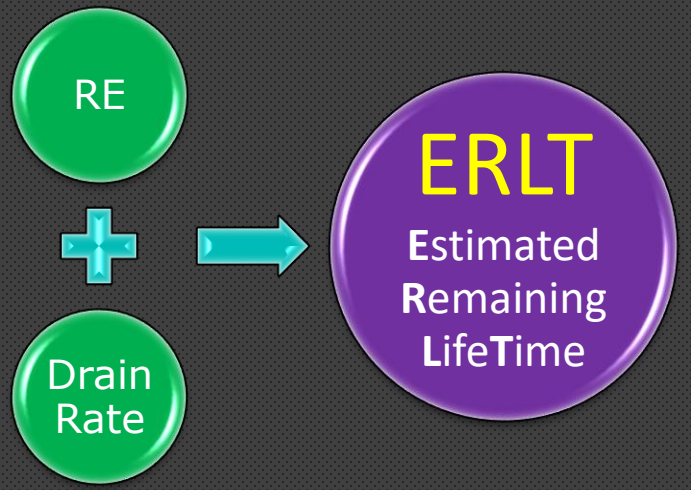

Metrics used
Cost Function
Parent Selection
Optimal Energy Efficient Routing

SEEOF: Metrics Used

- Drain Rate or slope
  - Used as a Base Metric for the proposed algorithm.
  - Based on traffic load condition
  - Avoid over-dissipation, and improves the energy consumption efficiently.
- Does NOT consider Remaining Energy.

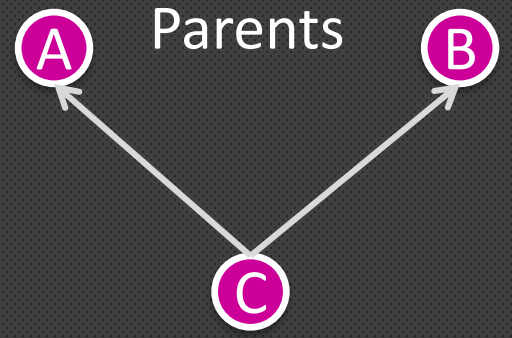


- $Drain\ Rate\ (m) = \frac{Amount\ of\ energy\ consumed}{Time}$
- $= \frac{Qo - RE}{t}$
- $m = \frac{RE}{S-t} = \frac{RE}{ERLT}$
- $\therefore \boldsymbol{ERLT} = \frac{\boldsymbol{RE}}{\boldsymbol{m}}$



Estimated Remaining Lifetime (ERLT)

- ERLT (=RE/m) alone is not sufficient
  - Only provides information about parents.
  - No information about parent-child link.
- Necessary to consider linkETX along with **ELRT**.
  - **Full information**
  - **Proper parent selection**



$ERLT_A > ERLT_B, ETX_A >> ETX_B$

Parent B suitable

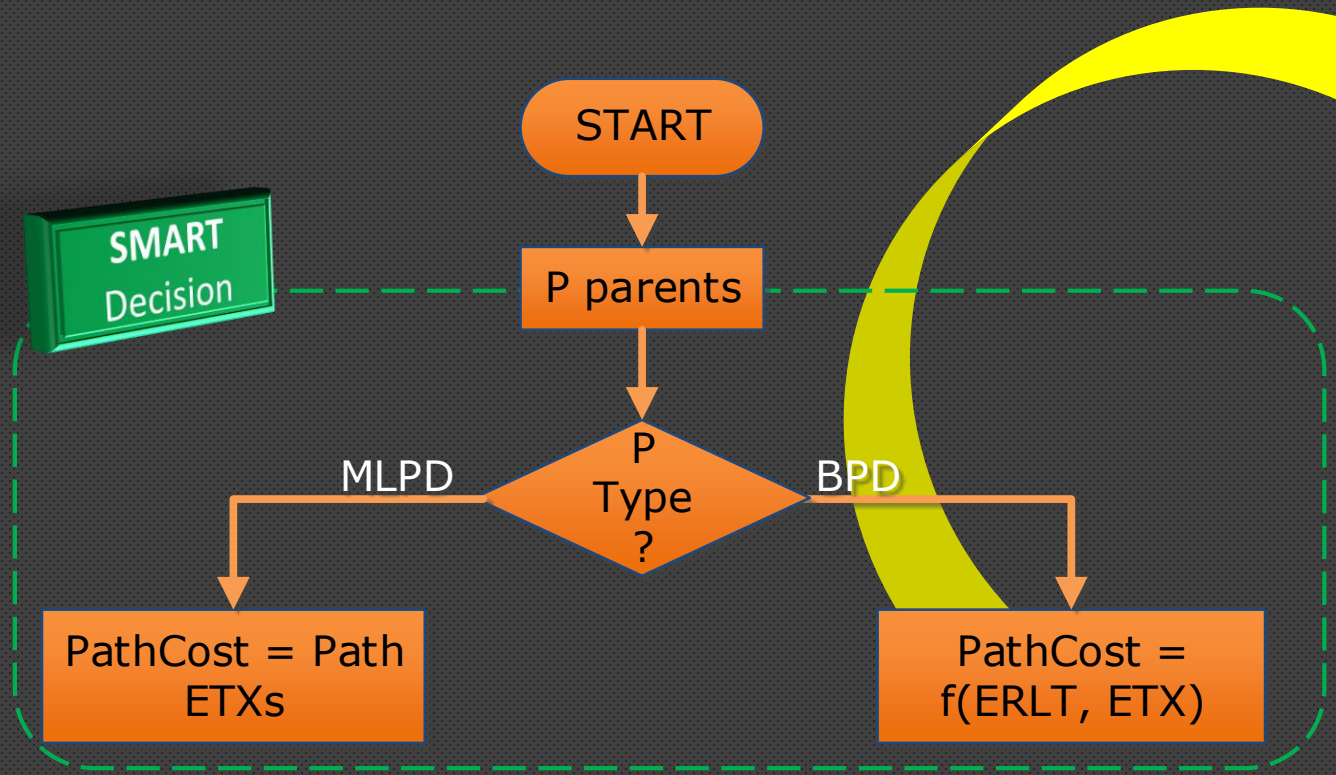
- Metrics Composition

Additive Combination

Lexical Combination

SEEOF Cost Function

MLPD : Mains Line Powered Device
BPD : Battery Powered Device



- New Cost Function for BPD
  - $Cost = \frac{ETX}{ETX_{TH}} + \frac{MAX_{LT} - ERLT}{ERLT_{TH}}$
  - Minimizable Cost Function
  - Better Control over Hysteresis

- ETX : link ETX
- ERLT : ERLT of parent
- MAX_{LT}: Maximum expected lifetime
- ETX_{Th} : Threshold in link ETX
- $ERLT_{Th}$: Threshold in ERLT

SEEOF Parent Selection

MLPD : Mains Line Powered Device
BPD : Battery Powered Device

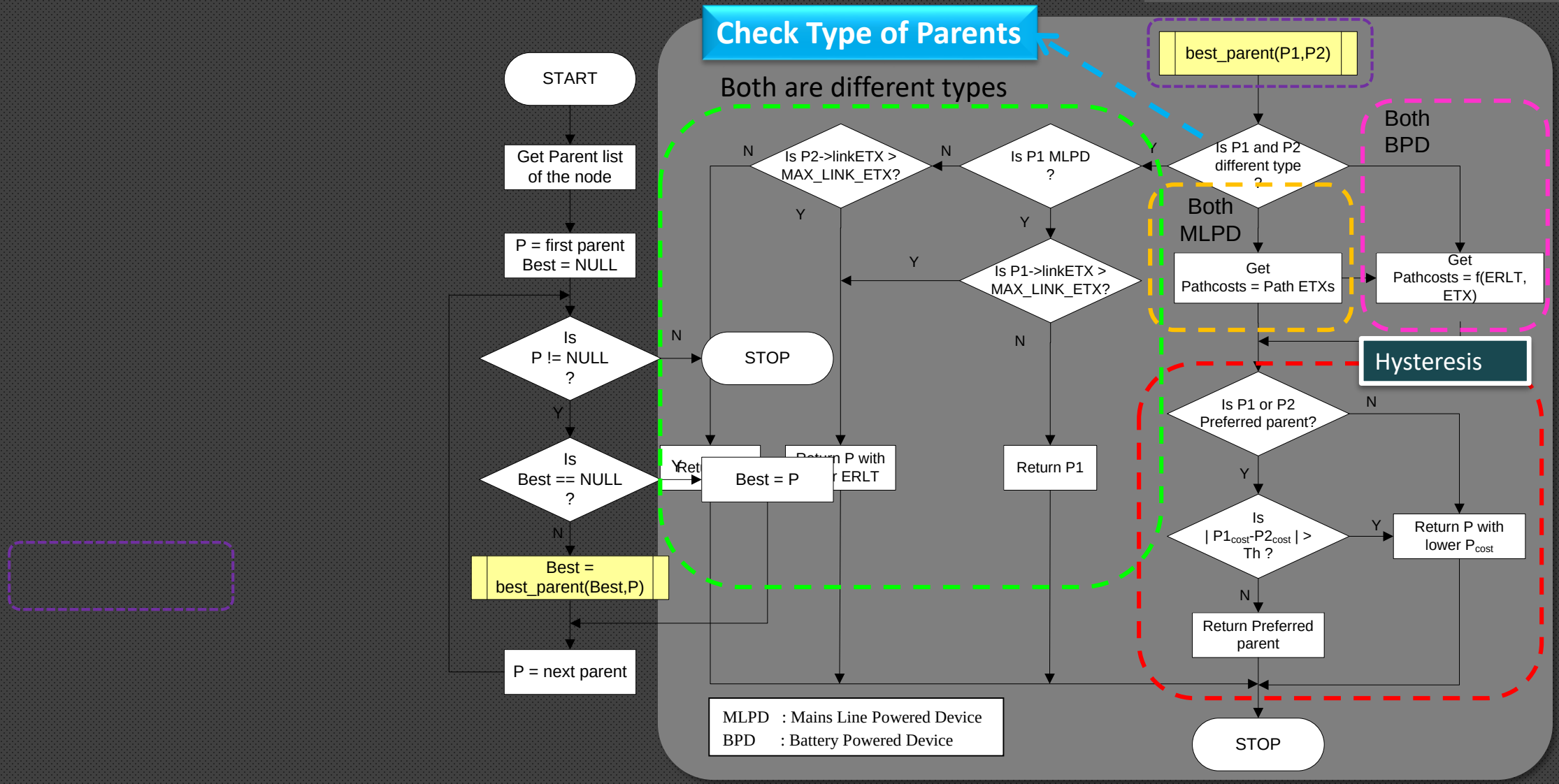


Figure 1: Parent Selection Algorithm to Select Best Parent

SEEOF Implementation to RPL

- Two Questions
  A. How to advertise the two metrics?
    1. ETX (Expected Transmission Count)
    2. ERLT (Estimated Remaining Life Time)

  B. How to know the type of the parents?

- EWMA Filter on ETX and Drain Rate Calculation

1. Advertising ETX Metric

0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1
RPLInstanceId								Version Number								Rank															
G	O	MOP			Prf			DTSN								Flags								Reserved							
DODAGID																															
Option(s)…																															

Figure: DIO Control Message Format

- As in MRHOF the ETX metric is carried by the 16-bit RANK field in the DIO message

SEEOF Implementation to RPL

2. Advertising ERLT Metric

- Measured in terms of time units (hours).
- Advertised using the Node Energy Object (NE Object) in DIO Message.

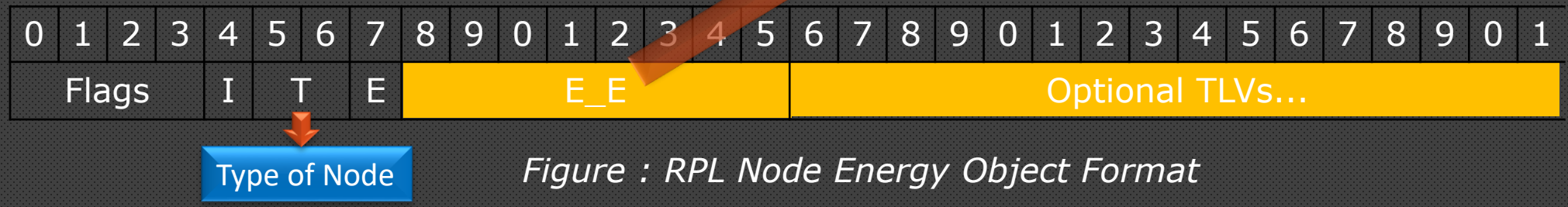


Figure : RPL Node Energy Object Format

- 8 bit E_E field
  - not sufficient to accommodate the entire ERLT.
  - May required higher number of bits.

Years	Hours	Bits required
5	43800	At least 15 bits
10	87600	At least 16 bits
15	131400	At least 18 bits
20	175200	At least 18 bits

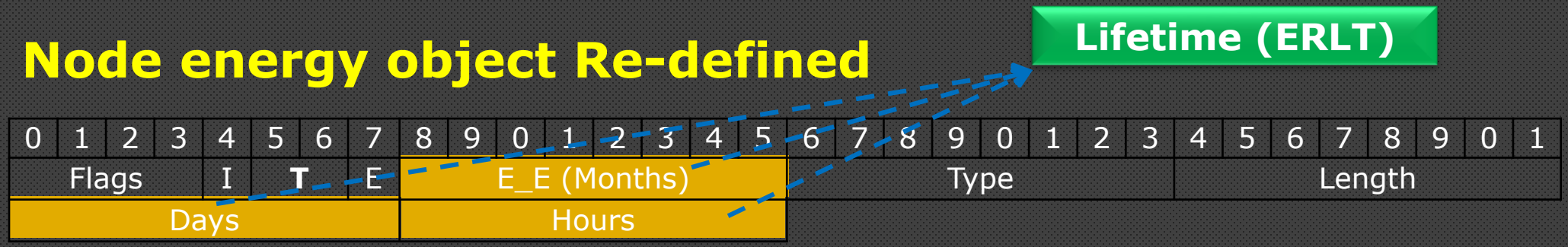
$1\ Day = 24\ Hours, \quad 1\ Month = 30\ Days = 720\ Hours$

- Utilize the **Optional TLVs** of the existing NE Object to carry full ERLT information.

SEEOF Implementation to RPL

MLPD : Mains Line Powered Device
BPD : Battery Powered Device

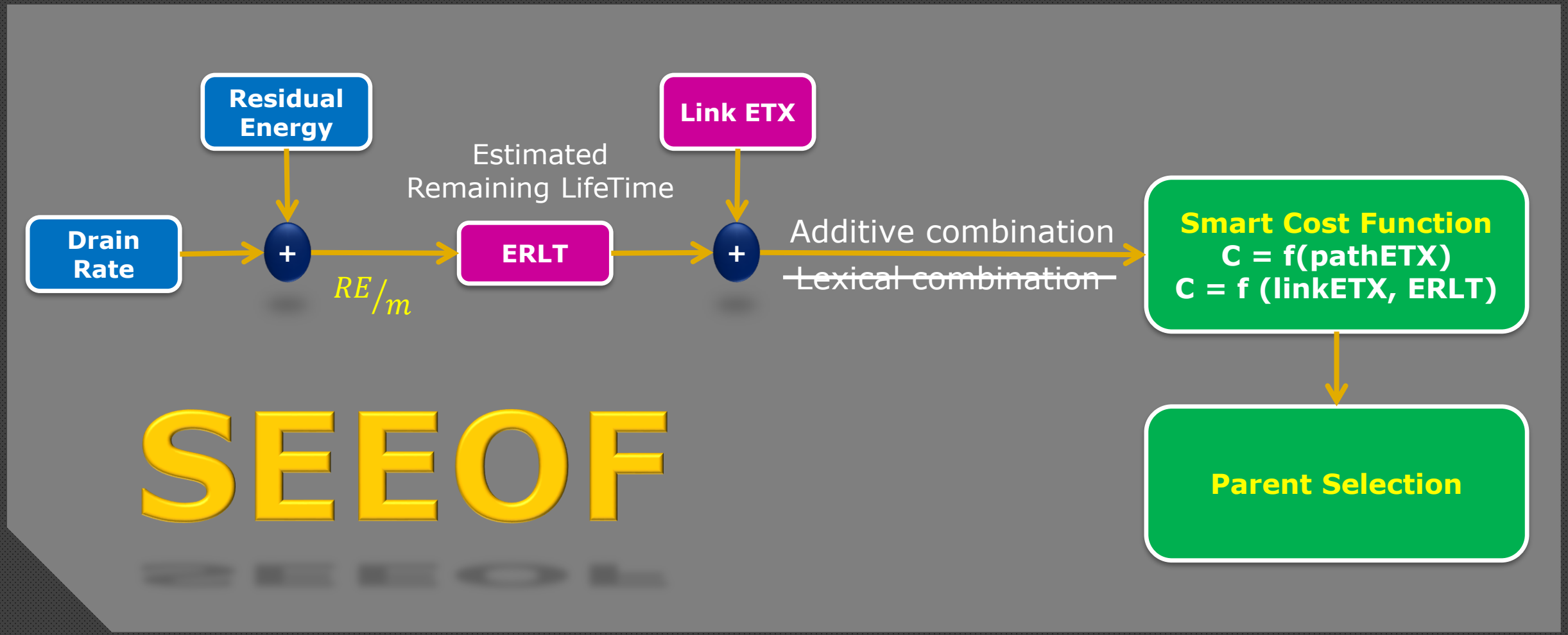
- **Node energy object Re-defined**



1. For **MLPDs**
   - 'T' → 0
   - 'E_E', 'Days', 'Hours' = 0xff
2. For **BPDs**
   - 'T' → 1
   - 'E_E', 'Days', 'Hours' = ERLT

- Max value of ERLT that can be advertised is up to 21 years.
- **Advantages** of using Node Energy Object.
  - No new metric Object has to be defined.
  - **'T'** flag → gives information about the type of the parent (**MLPD** or **BPD**) necessary for optimal and energy efficient parent selection in **SEEOF**

SEEOF: Summary



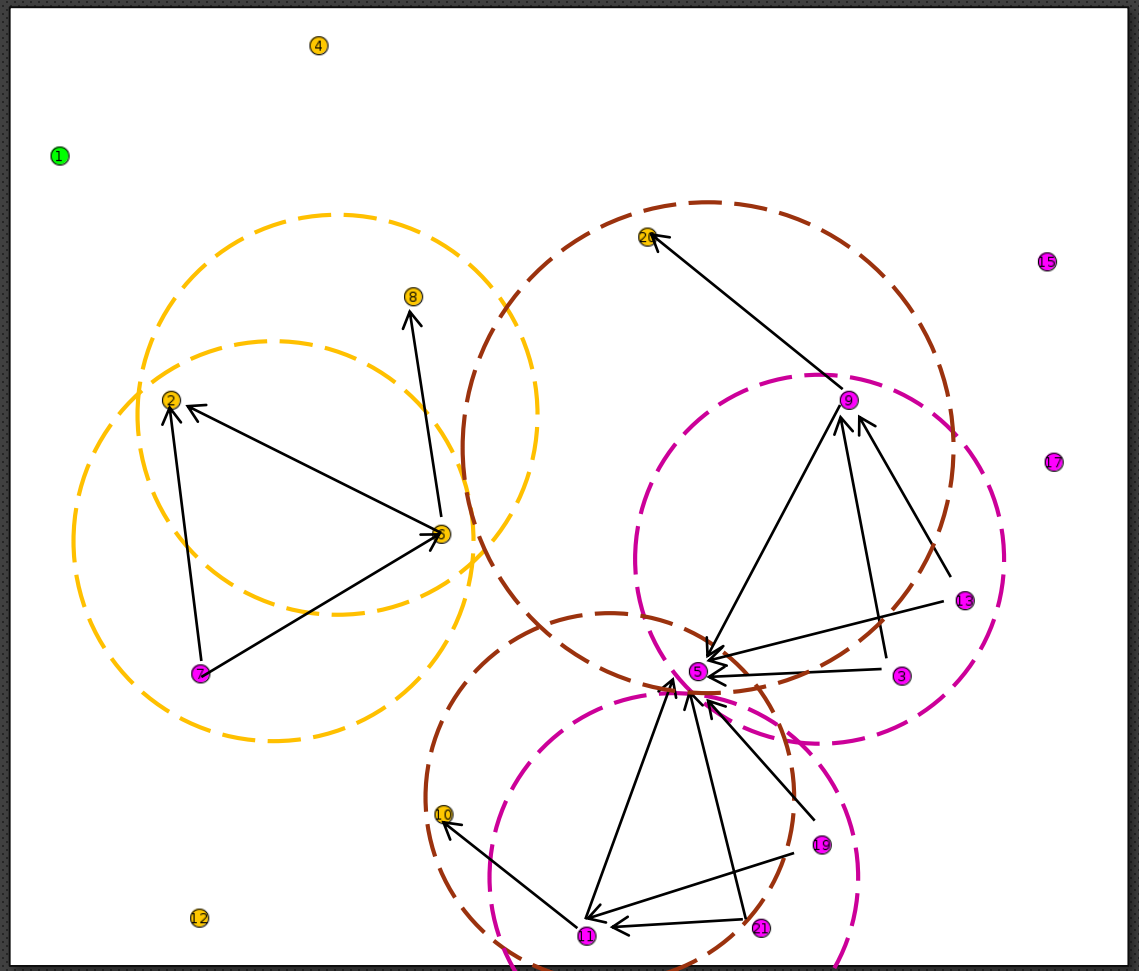
Simulation

- The performance evaluated using Cooja Simulator with ContikiOS.
- Compared with MRHOF using ETX metric
  - better suited in terms of energy consumption, PDR and latency

Parameters	
Protocol	RPL
Device Model	TMote Sky (MSP430 + CC2420)
Number of Nodes	18
Radio Medium	UDGM-Distance Loss
Battery Capacity	3.65AH, 1.6V
RX Success Ratio	40%, 60%, 80%, 100%
OF	**SEEOF, MRHOF with ETX**
Simulation Time	60 Hours

Simulation Topology

MLPD : Mains Line Powered Device
BPD : Battery Powered Device

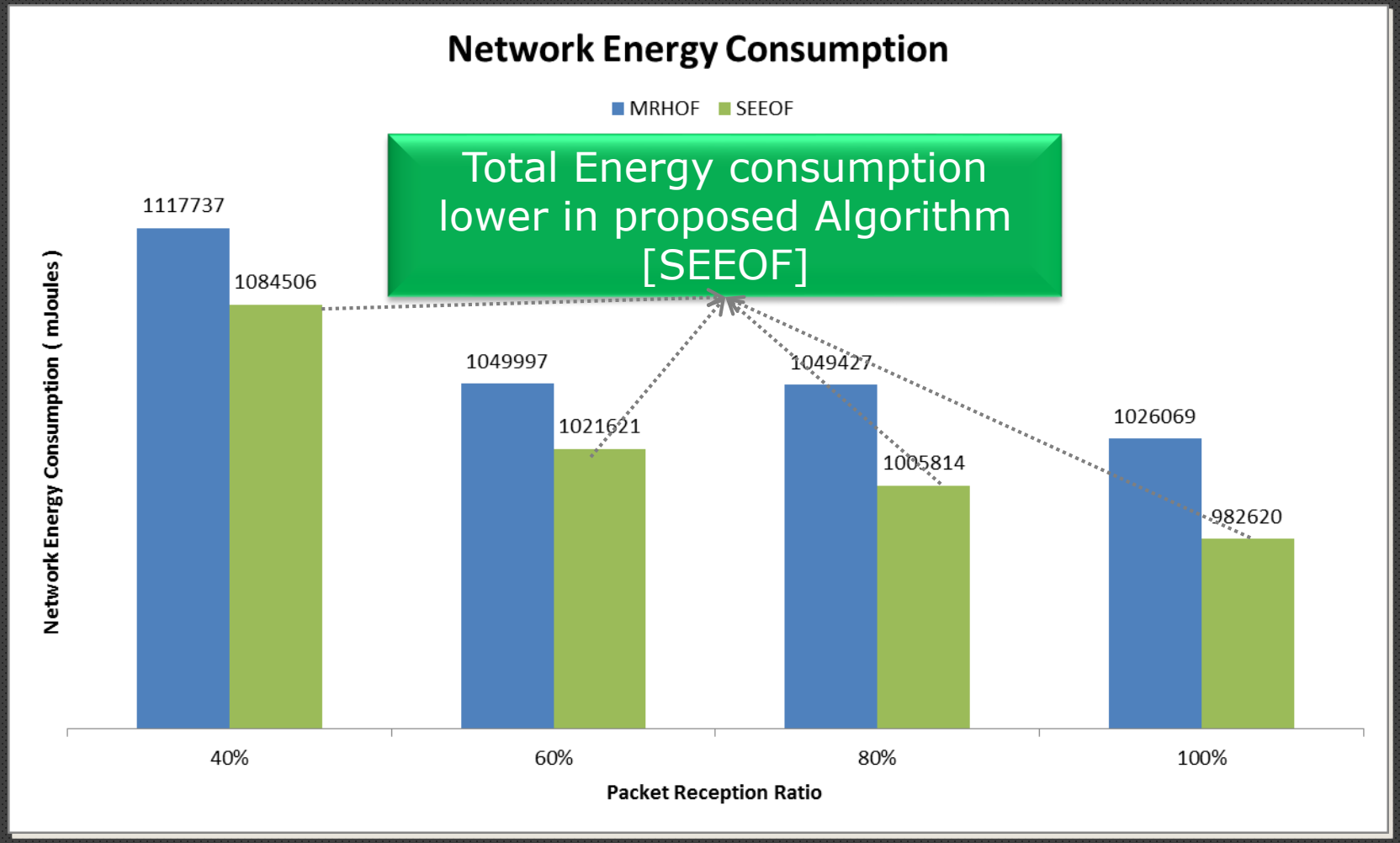


- Sink (Node 1)
- MLPD (Even)
- BPD (Odd)
- 18 nodes
- All cases involved
  - **MLPD** Parents
  - **BPD** Parents
  - **Hybrid** Parents

- Result Evaluation: only for the BPDs at the end of the simulation time

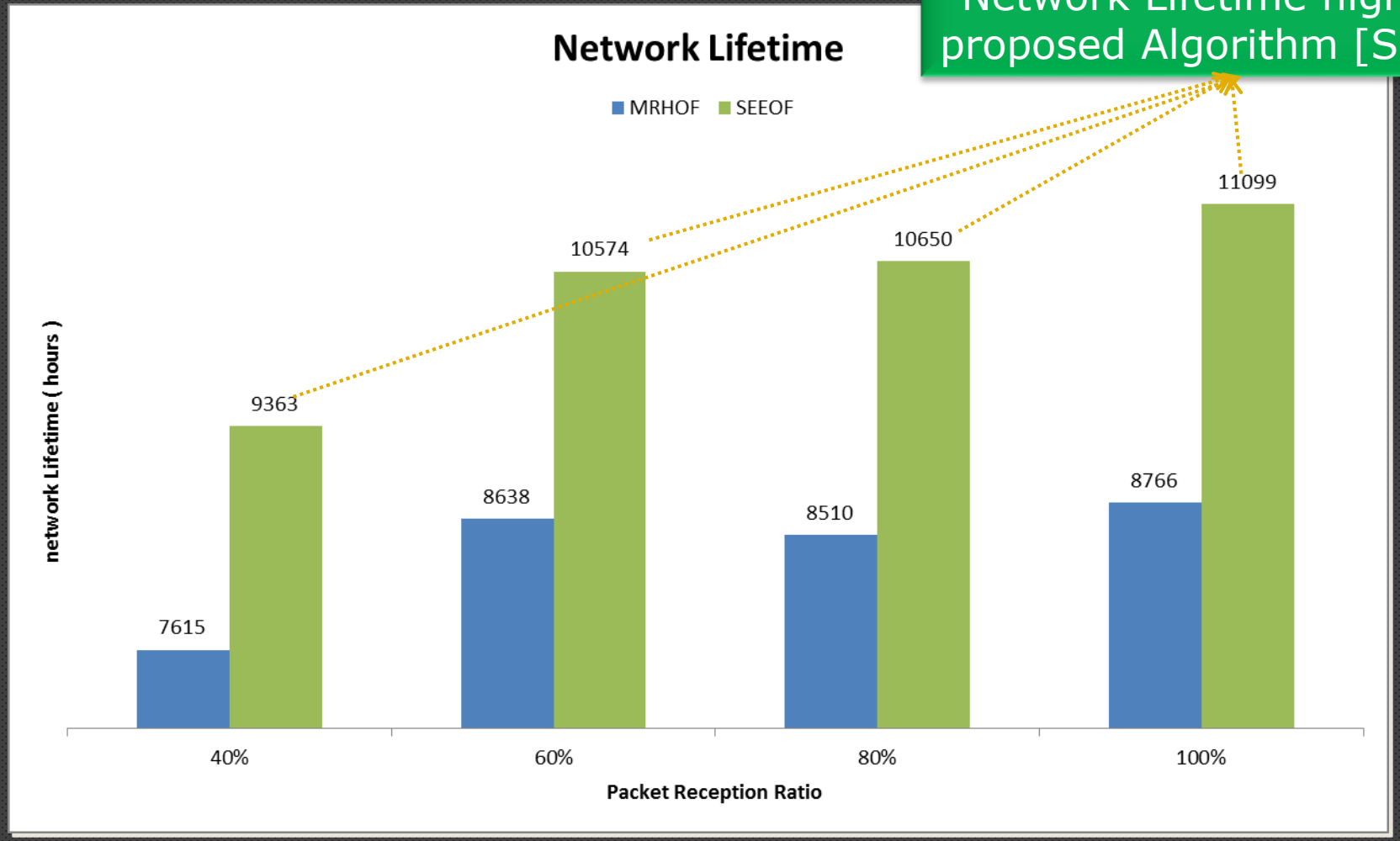
Graphs (Network Behavior)

- Total energy consumed by the BPDs in the network



Graphs (Network Lifetime)

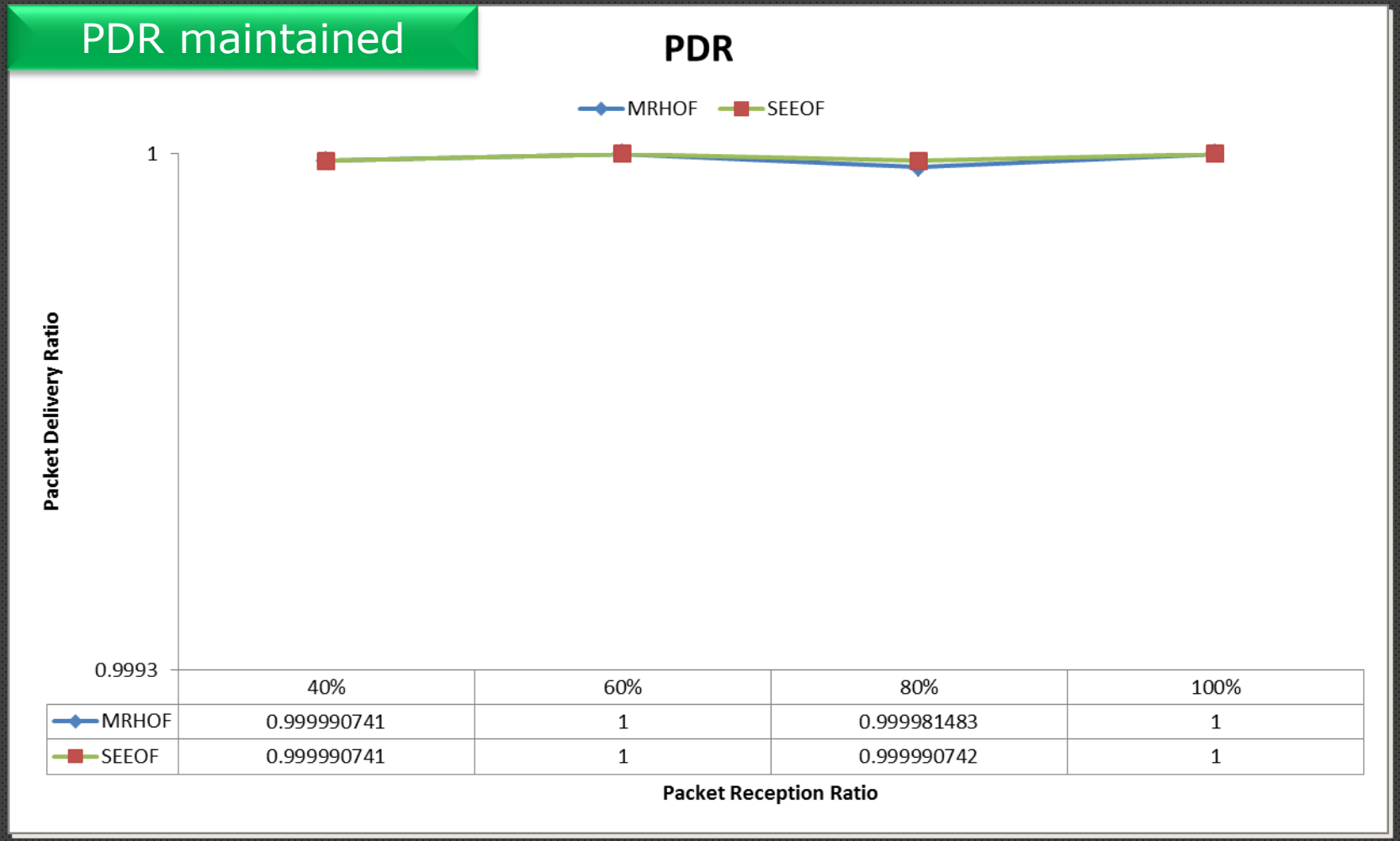
- Minimum lifetime among all the BPDs in a network



Graphs(End to End PDR)

- $PDR = {Total\ packets\ received}/{total\ packets\ sent}$; MAINTAINED

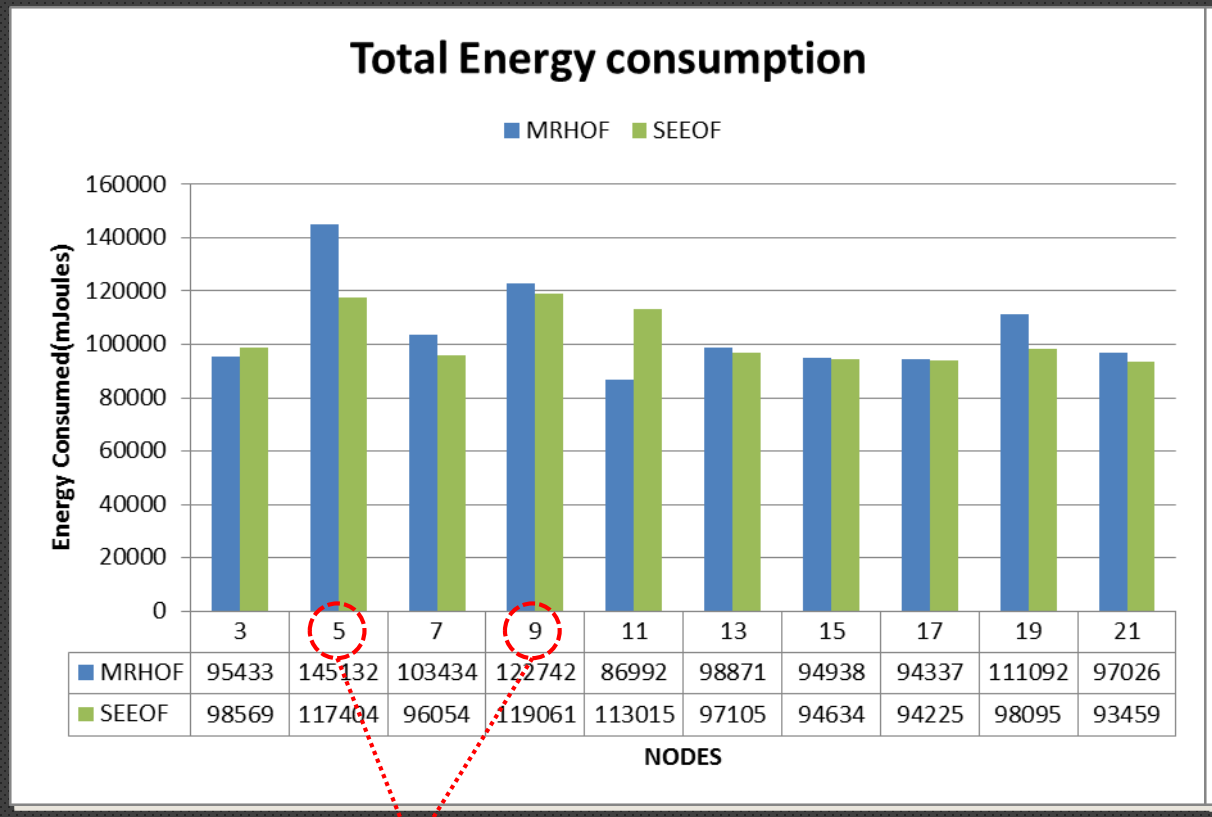
PDR maintained



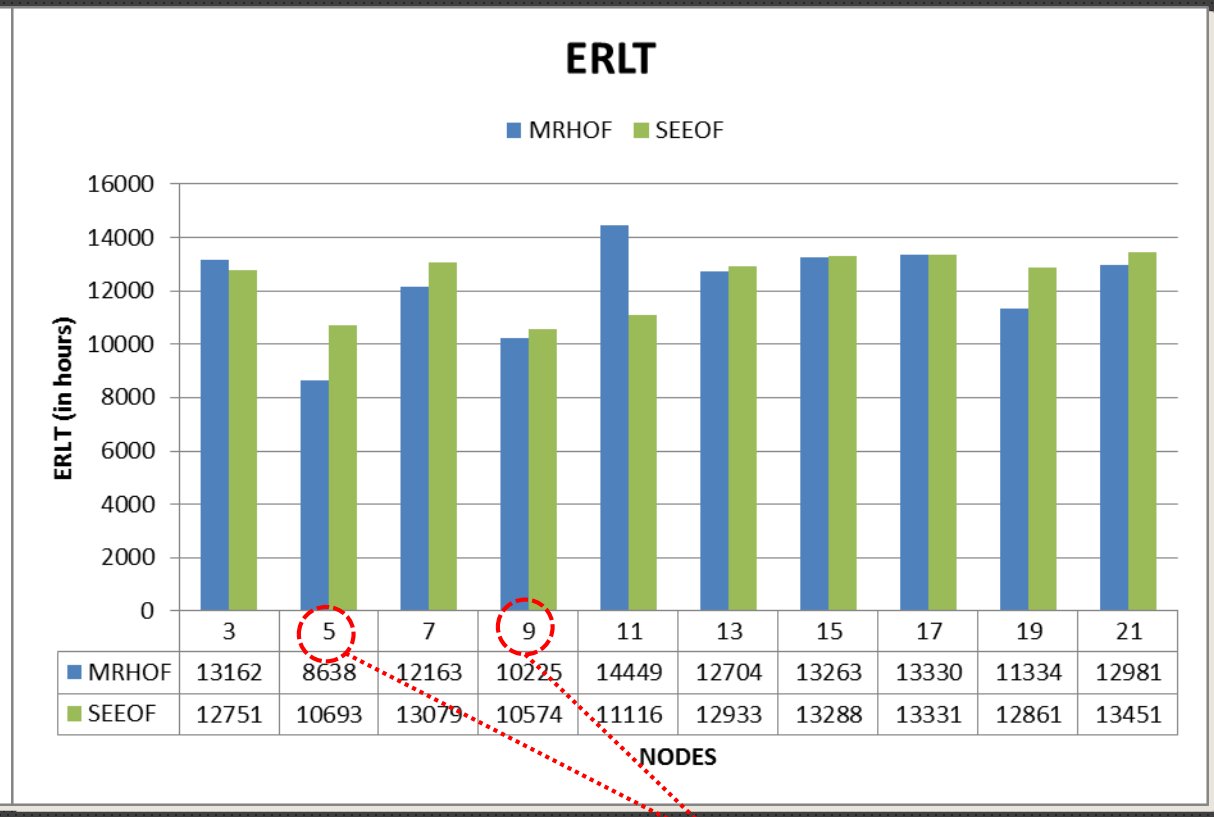
	40%	60%	80%	100%
MRHOF	0.999990741	1	0.999981483	1
SEEOF	0.999990741	1	0.999990742	1

BPD Router Behavior

- (60% Reception ratio)



	3	5	7	9	11	13	15	17	19	21
MRHOF	95433	145132	103434	122742	86992	98871	94938	94337	111092	97026
SEEOF	98569	117404	96054	119061	113015	97105	94634	94225	98095	93459



	3	5	7	9	11	13	15	17	19	21
MRHOF	13162	8638	12163	10225	14449	12704	13263	13330	11334	12981
SEEOF	12751	10693	13079	10574	11116	12933	13288	13331	12861	13451

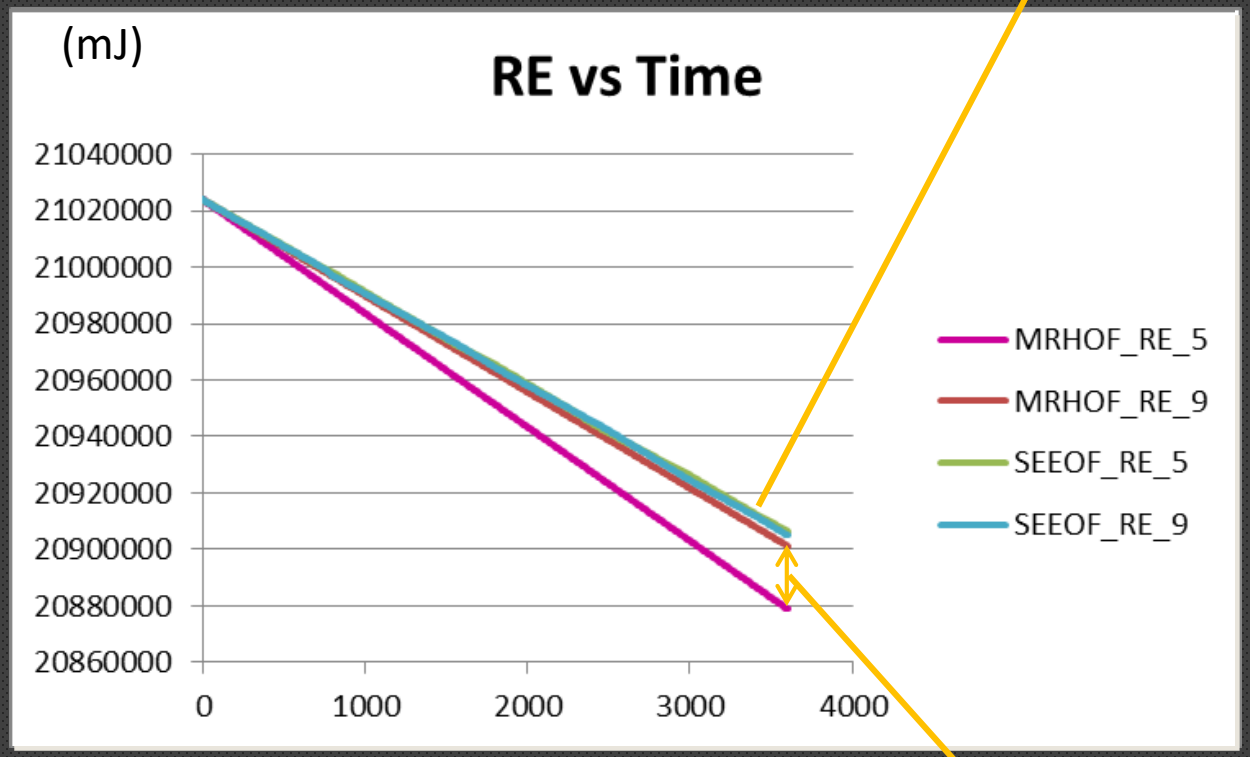
Higher Energy Consumption

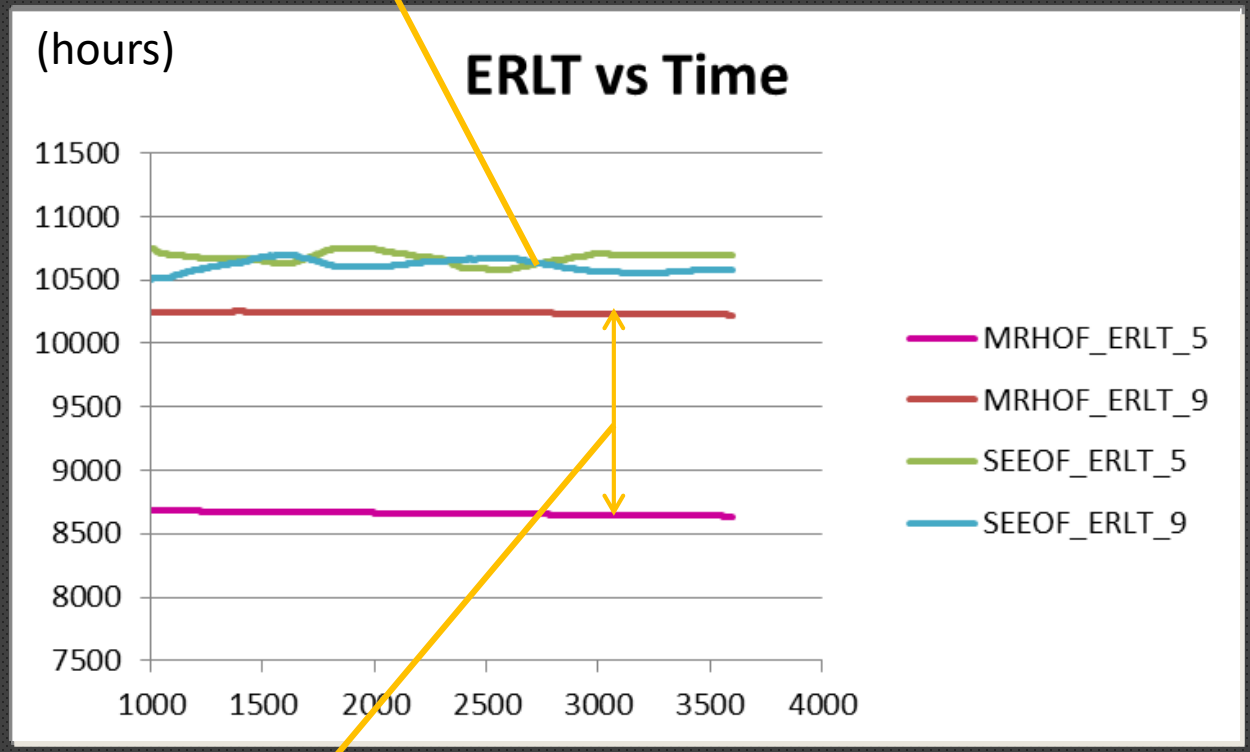
Node 5 & 9 are **BPD Routers**

Lower Lifetime

BPD Router Behavior (Nodes 5 and 9)

Much Balanced





Large Gap

Conclusion

- New parent selection algorithm (**SEEOF**) developed
  - Enabling gas/water meters work in parallel with meshed network containing electric meters.
  - New Cost function for BPDs
    - Link quality
    - Node energy in terms of lifetime
- Implemented to RPL
  - Metric ERLT advertised using existing NE object.
- Performance evaluation in ContikiOS with Cooja.
- Simulation results show
  - Energy consumption is balanced more efficiently (Fair Distribution).
  - Improvement in the network lifetime (upto 27%).

Future Work

- Implementation on the test-bed
- Scalability in terms of more number of BPD hops

Thank You...

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