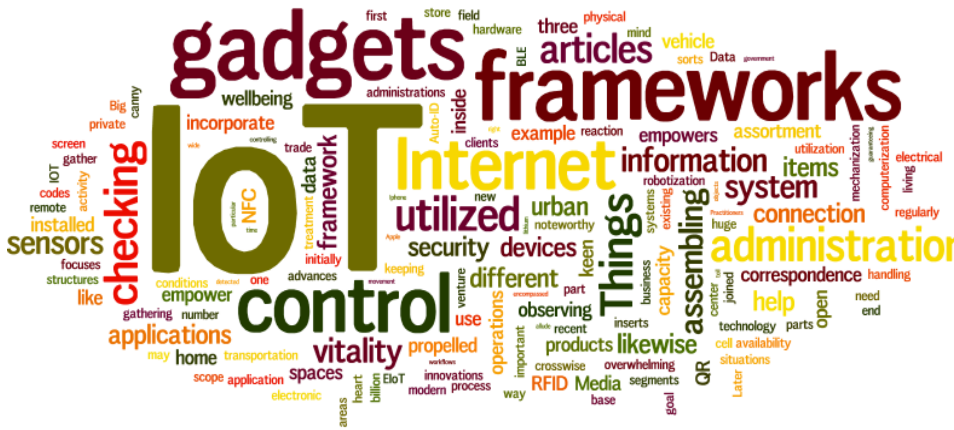
CS578: Internet of Things



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"We must have life-building, man-making, character-making assimilation of ideas." – **Swami Vivekananda**

RPL Objective Functions

- **Objective Function Definition:**

- An Objective Function specifies how RPL [1] selects paths
- Define how nodes translate one or more metrics into a rank.
- Metrics are chosen based on the objective of the RPL

- **Standardized Objective Functions used:**

- OF0: Objective Function Zero
- Minimum Rank with Hysteresis OF

RPL OF0 [2]

➢ **OF0 Goal:**

- The Goal of the OF0 is for a node to join a DODAG Version that offers good enough connectivity to a specific set of nodes

➢ **OF0 operations:**

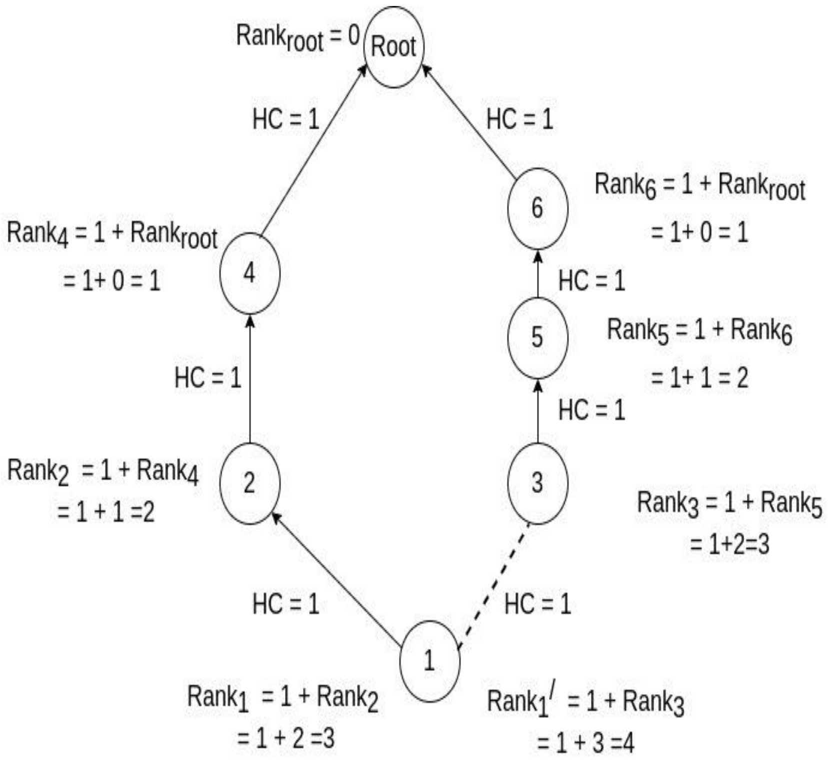
- Computing Rank - computes a variable step_of_rank
- The step_of_rank is used to compute the amount by which to increase the rank along a particular link
- For Of0 step_of_rank calculation depends on a static metric - Hop count (Provides good connectivity)

➢ **Demerit:**

- OF0 does not really use a metric to measure the loads of selected parent – leads to depletion of battery lifetime
- Some links selected only on the basis of hop count may have bad link quality, so can lead to packet losses

➢ **Rank Calculation:**

- Rank (I) = rank of parent + cost for choosing the parent (cost / routing metric
- For OF0, **hop count** is used as cost metric



RPL MRHOF [3]

- **MRHOF Goal:**

- Selects routes that minimize a metric, while using **hysteresis** to reduce churn in response to small metric changes.

- **MRHOF operations:**

- MRHOF uses **Expected Transmission Count (ETX)** metric **by default** that allows RPL to find the stable minimum-ETX paths from the nodes to a root in the DAG instance.

- After finding minimum cost paths, it switches to that minimum Rank path only if it is shorter (in terms of path cost) than the current path by at least a given threshold. This mechanism is called **"hysteresis"**.

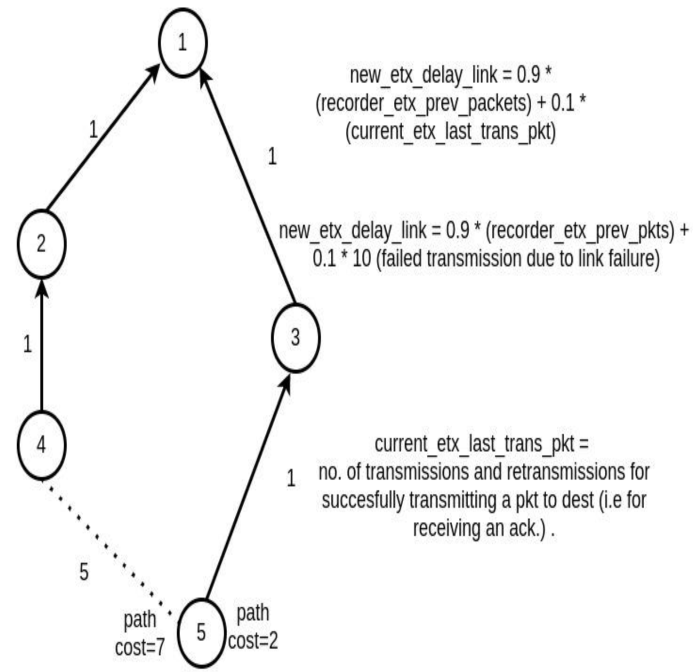
- **Computation of ETX:**

- **ETX = (s + f) / s**, where s is the number of packets successfully delivered to the neighbour node and f denotes the number of packets failed to be delivered

- In other words, **ETX is the number of transmissions and retransmissions** for successfully transmitting a packet to the destination (successfully transmitted means the sender has received the acknowledgement from the receiver)

link failure 5->3

ETX (5->3)	Diff.
1	-4
1.9	-3.1
2.71	-2.29
3.43	-1.56
4.09	-0.90
4.68	-0.31
5.21	0.21
5.69	0.69



- **Demerit:**

- Only monitors currently active links

- Considers only single routing metric ETX for parent selection

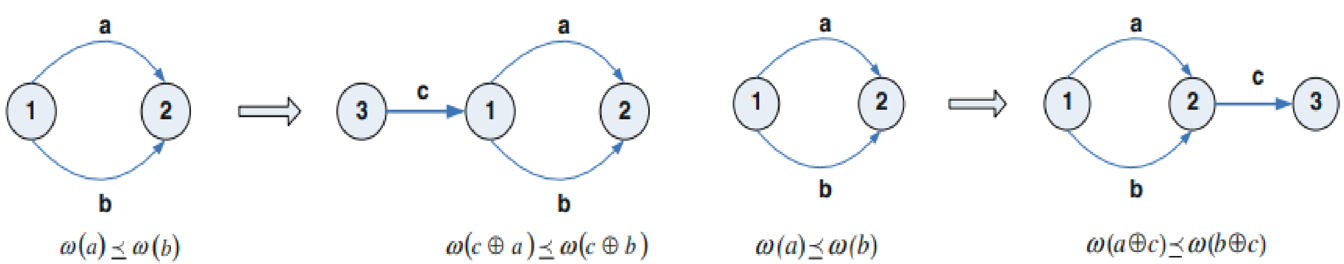
- Therefore, researchers proposed methods to combine more than one routing metric to satisfy QoS requirements for different applications

Routing metrics Properites[7]

➢ **Routing metric properties:**

- **Monotonic** -
- Monotonicity means that the weight of a path does not “decrease” (i.e. gets better) when prefixed or suffixed by another path.
- If the metric is monotonic, then every network can be made free of loops, thereby ensuring convergence of the routing protocols for distance vector protocols like RPL.

- **Isotonic** -
- isotonicity property essentially means that a routing metric should ensure that the order of the weights of two paths is preserved if they are appended or prefixed by a common third path.
- If the algebra is isotonic, then the paths onto which routing protocols converge are optimal for distance vector protocols.



Note: Monotonicity and strict isotonicity of the employed routing metric guarantees the **optimality, consistency and loop-freeness of any routing protocol type**

Combination of Routing metrics

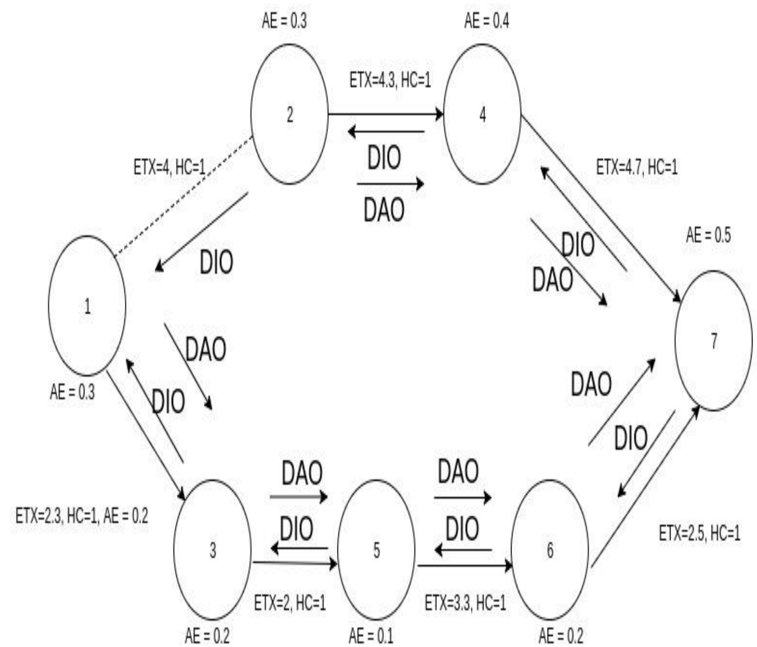
➢ **Routing metric combination approaches:**

- **Lexical metric composition** -
- The primary routing metrics are prioritized and when a path offers a better weight **with respect to the first metric** then it will be preferred regardless of the path weights of the rest metrics.
- The second metric is taken into account only if more than one paths map to **equal weights for the first metric**.

$$(\omega_1(\alpha), \omega_2(\alpha)) \preceq_{lex} (\omega_1(b), \omega_2(b)) \Leftrightarrow$$
$$(\omega_1(\alpha) \prec_1 \omega_1(b)) \vee (\omega_1(\alpha) = \omega_1(b) \wedge \omega_2(\alpha) \preceq_2 \omega_2(b))$$

- **Additive metric composition** -
- In contrast to the lexicographic composition, in this case the two primary metrics should hold the same order relation so that the produced composite additive routing metric makes sense

$$(\omega_1(\alpha), \omega_2(\alpha)) \preceq_{add} (\omega_1(b), \omega_2(b))$$
$$\Leftrightarrow \omega_1(\alpha) + \omega_2(\alpha) \leq \omega_1(b) + \omega_2(b)$$



Paths get selected on basis of ETX

Objective function to use for Advanced Metering Infrastructure (AMI) networks [5]

➢ **AMI networks:**

- **Decide Network topology first**
- AMI (advanced metering infrastructure) is a kind of wireless sensor networks for **two-way communication** between smart meters and city utilities.
- Static and Mobile scenario
- Number of nodes - approx. 1000

- **Decide the objectives of the IoT application**
- In AMI networks,the resource constraints of nodes demand for **energy conservation, link stability and traffic load balance**
- Therefore, in AMI networks, **node energy, Expected Transmission Count (ETX) and child node count (CNC)** should be considered for energy conservation, link stability and traffic load balance. Moreover, for some real-time applications of AMI networks, **End to end delay (EED) and Hop Count (HC)** also should be considered
- **Traffic Characteristics**
- AMI must support traffic generated at a variety of sources(meters, data collectors, etc.) and the AMI network must fulfill the needs of different natures of traffic while it may face constraints.

Objective function to use for Home and Building Automation [6]

- **Home and Building Automation:**

- **Decide Network topology first**
- Static scenario – Sensors and actuators in a home or building typically have **fixed physical locations** and will remain in the same home or building automation network.
- Number of nodes – usually 100
- One border router -. This configuration will happen in homes where home appliances are controlled from outside the home, possibly via a smart phone, and in many building control scenarios.
- **Decide the objectives of the IoT application**
- **Timely and Reliable response** - a light not switching on after entry into a room may lead to confusion and a profound dissatisfaction with the lighting product.
- Objective function uses - **ETX, End to end delay**
- **Traffic Characteristics**
- Looking over time periods of a day, the **networks are very lightly loaded.** However, bursts of traffic can be generated by, for example, incessant pushing of the button of a remote control, the occurrence of a defect, and other unforeseen events.
- 2) If the light does not turn on at short notice, a user may activate the controls again, thus causing a sequence of commands such as Light{on,off,on,off,...} or Volume{up,up,up,up,...} - **creates load in network**

Objective function to use for healthcare And medical applications – Case study [4]

KAUH’s medical hospital at Jordan University of Science and Technology

Objective function to use for healthcare And medical applications – Case study

- A,C, D wards- monitor environmental factors like tempreature, humidty, pressure and B ward- ICU
- Data is critical in ward B – has to be given more attention as compared to wards A,C,D because in A,C,D environment is stable
- Data traffic classification– **high-critical (HC) , critical (C), medium-critical (MC), and low-critical (LC) data or periodic.**
- Cardiac Care Unit (CCU) – HC, ICU – C, Other medical department – MC, health environmental parameters - LC / periodic
- Each floor combines two or more traffic types
- **MRHOF** is suitable to be used with the instances of highcritical, critical, and medium-critical data traffic, while **OF0** can be used for the instance which used periodic data traffic

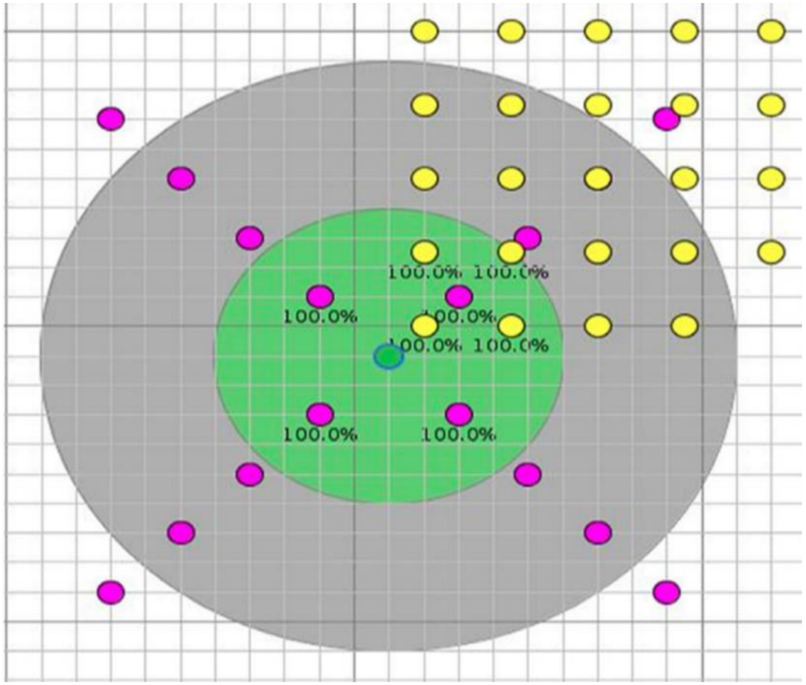
The Floor	RPL Instances	Number of Nodes	Traffic Type	Objective Function
1st floor	Instance 1	24	Critical	MRHOF
	Instance 2	16	Periodic	OF0
9th floor	Instance 1	32	Critical	MRHOF
	Instance 2	20	Medium-critical	MRHOF
	Instance 3	16	Periodic	OF0
11th floor	Instance 1	48	High-critical	MRHOF
	Instance 2	24	High-critical	MRHOF
	Instance 3	12	High-critical	MRHOF
	Instance 4	16	Periodic	OF0

Data Traffic Type	Sending Interval	Packet Size
High-critical	Average of 5 s	16 bytes
Critical	Average of 10 s	16 bytes
Medium-critical	Average of 15 s	32 bytes
Low-critical (periodic)	Every 5 min	48 bytes

Simulation Topology

Successful Reception Ratio	Traffic Type	Single Instance	Proposed Approach
100%	Overall	7.10	0.04
	Critical	7.12	0.04
	Periodic	6.06	0.05
85%	Overall	9.72	0.04
	Critical	9.79	0.04
	Periodic	5.67	0.06
70%	Overall	11.93	0.05
	Critical	12.03	0.05
	Periodic	6.45	0.06

Latency (seconds)



First Floor Topology

The results show that the proposed approach using multiple RPL instances outperforms the use of single RPL instance in terms of overall average PDR in all RX values. Also, the proposed approach provides a clear improvement for the PDR of the critical traffic (ICU generated data)

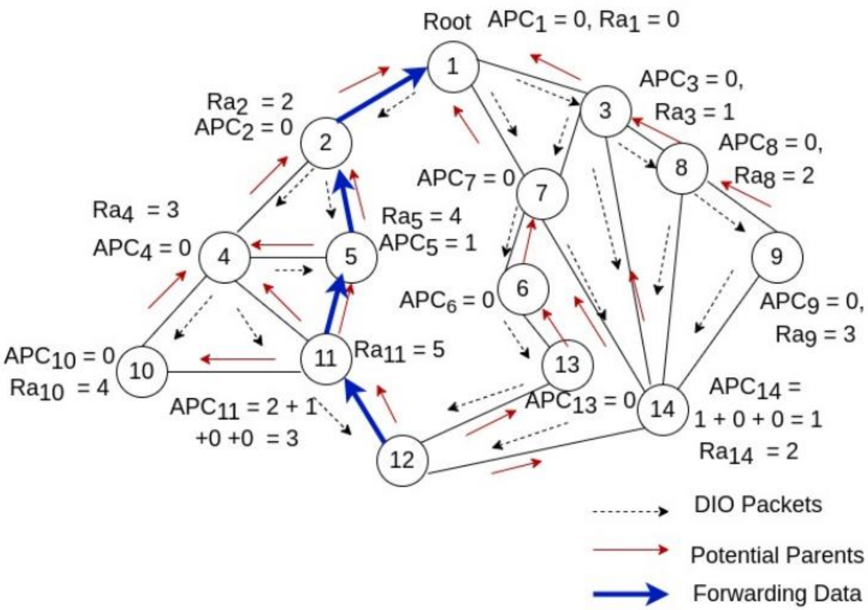
Our proposed work

Paper title- **Achieving Hard Reliability in RPL for Mission-Critical IoT Applications (Accepted in World Forum on Internet of Things)**

Contributions:

- A **new objective function** is designed for path cost calculation. In the path cost calculation, a new metric called **alternative parent connectivity (APC)** has been used which can take care of the higher reachability probability of a packet.
- **Maximum achievable reliability** is derived based on the reliability requirement of an MC-IoT application.
- **Dynamic selection of k number of parents** based on the path cost and reliability requirement is proposed.
- **Simulation based analysis** is performed using Cooja simulator to validate the proposed work.

APC metric computation



$$APC_i = AP_i + \sum_{n=1}^{AP_i} AP_{i,n}$$

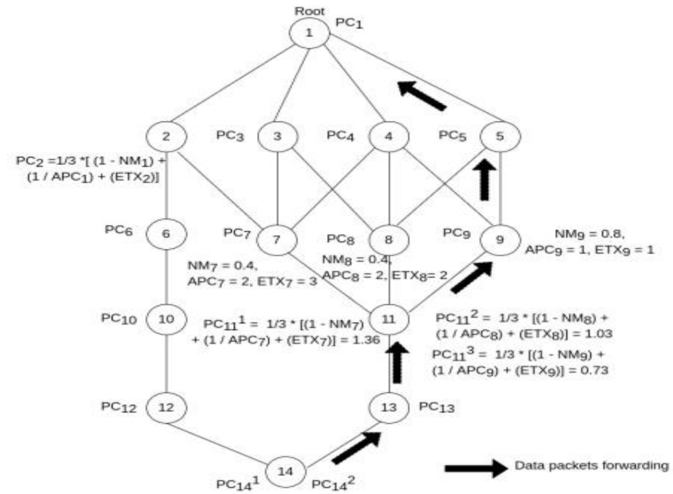
$$AP_i = PP_i - 1$$

$$APC_{11} = AP_{11} + \sum_{n=1}^{AP_{11}} AP_{11,n}$$
$$= 2 + (1 + 0 + 0) = 3$$

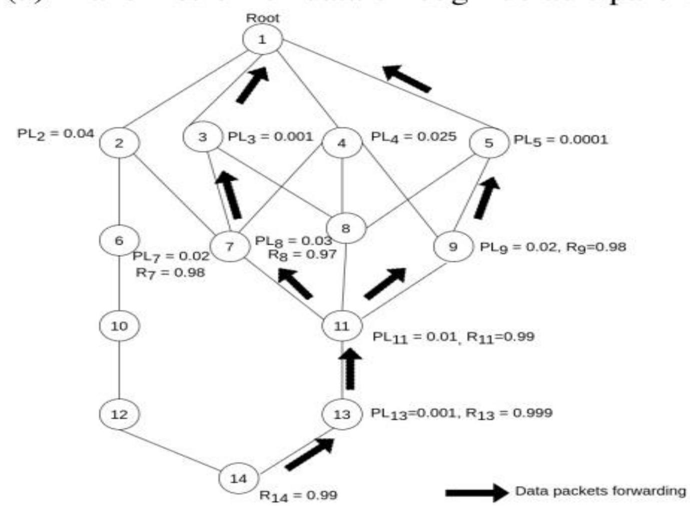
Data transmission

$$PC_j = \theta * \sum_{node=j}^{node=root} (1 - NM_{node})$$
$$+\beta * \sum_{node=j}^{node=root} (\frac{1}{APC_{node}})$$
$$+\gamma * (ETX_{i\to j} + \sum_{node=j}^{node=root-1} ETX_{node->node+1})$$

$$PC_k = \theta * \sum_{node=k}^{node=root} (1 - NM_{node})$$
$$+\beta * \sum_{node=k}^{node=root} (\frac{1}{APC_{node}})$$
$$+\gamma * (ETX_{i\to k} + \sum_{node=k}^{node=root-1} ETX_{node->node+1})$$



(a) Transmission of data through default parent



(b) Transmision of data through multiple parent

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Thanks!