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# RPL Routing Protocol in Smart Grid Communication

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## ABSTRACT

Smart grid communication emerged to solve the old grid problems. Advanced Metering Infrastructure (AMI) network is a part of smart grid communication, organized of smart meters and concentrators. Concentrator is the gateway for a network of meters sending information in a multihop manner. Reliability and low latency are the major criteria in AMI networks which can be achieved by application configurable routing protocol. Routing Protocol for Low Power and Lossy Networks (RPL) defined by routing over Low power and Lossy networks (ROLL) working group is a multihop routing protocol preferred to AMI networks. Objective function specifies parent selection and route construction base on determined constraints and metrics. In this paper an Objective Function (OF) using Expected Transmission Count (ETX) as a criteria to select the parent node is evaluated with the proposed hop count based version of Objective Function 0 (OF0) using only hop count as the selection metric. Results showed that the proposed objective function performs better than the other one in case of Packet Delivery Ratio (PDR) and average end to end delay.

**Keywords:** *Smart Grid, AMI, RPL*

## 1. INTRODUCTION

Today conventional power grid is ill-suited for new electrical requirements since there is inefficiency in automation, visibility and information feedback. The need for electrical energy is increasing and old systems generate more than users consumption to prevent from outage while they are incapable to store so much energy due to expensive storage equipment [1]. There are fossil consumer electricity generators which are turned on in peak load times. They enter noticeable amount of CO2 to atmosphere in addition that fossil is a valuable and rare source of energy. The real electricity demand is much lower than what load forecaster model says so electricity wasting is not preventable as gird storages are really expensive to store additional electricity [2]. Smart grid communication is the solution for declared problems. It is a communication network reporting user demand of energy to provision center to balance the amount of demanded and produced energy. The communication network provides management operation, outage and failure report, and of course dynamic pricing.

Smart grids is a new emerging technology providing user and utility center communication to provide more reliable, real time and reduced cost services. It provides communicational infrastructure gathering information of users in real time mode to analyze and support user with a higher classes of services. The evolution of smart grid enhances reliability, utilization and efficiency with the help of modern power grid infrastructure, automated activities, sensing, smart control and metering technologies. Equipment failure, outage, excessive demands and different kinds of problems can be discovered in real time with the help of online monitoring and maintenance provided by communication networks.

Communication infrastructure is an important factor in electric power grid cooperation. Smart grid goals achievement severely depends on communication quality level. Low network latency, real time data delivery and reliability are necessary requirements of smart grid communication [3].

The large scale communication network of smart grid is constituted of three main parts: access area, distribution infrastructure and core network. Homes, buildings, industrial collection organize the access area. They are the infrastructures delivering smart gird services to end customers and providing user contribution in electricity production. Distribution infrastructure enables the collection of electricity usage data and management commands delivery. Advanced metering Infrastructure (AMI) resides in the second part and is a communication network interconnecting smart meters embedded in user location to data aggregation and control center. The third part is responsible for management and control based on data aggregator center received data. Core network is a wide area network providing facilities to interconnect control centers and data aggregator stations located in different area in power grid network [4].

AMI network provides utility center with the information about quality of power and quantity of consumption at end customer premise. It is possible to balance electricity generation level with user demand. Dynamic electricity pricing is applicable by AMI network charging end user with lower price when it is not peak load time. Collection of smart meters and gateway nodes is an AMI network. Gateway node is in responsible for gathering information from smart meters and forwarding them toward data aggregators. Smart meters installed in homes, offices and other user promise transmits information about usage amount, fault occurrence and etc. to utility provider. Smart meters are interconnected by wire technology as power line communication (PLC) or wireless as low power Wi-Fi or IEEE 802.15.4.

Devices in AMI networks are embedded devices with low computational and storage capability using low data rate and lossy radio communications. These kinds of networks are called Low-power and Lossy Network (LLN). Internet Engineering Task Force (IETF) designed RPL (Routing Protocol for Low Power and Lossy Networks) routing protocol suitable for LLN. Now RPL is the most preferred routing protocol for large scale AMI networks.

In this paper we concentrate on AMI networks in smart grid communication. The considered AMI network consists of many smart meters and one gateway node connected to backbone network sending gathered information from meters to utility data center. These two elements organize a routing tree whose root is the high bandwidth backbone connected gateway node. Meters are low bandwidth and low rate embedded resource constrained devices using high loss rate IEEE 802.15.4 radio communication.

The rest of the paper is as follows. An overview of related works is presented in section 2. Section 3 is about RPL routing protocol. Objective Functions are discussed in section 4. Simulation results are presented in Section 5 and finally conclusion is in section 6.

## 2. RELATED WORK

V. Kathuria et al. [5] compared RPL and Adhoc On Demand distance Vector protocol (AODV) in simulated large-scale smart meter network. RPL outperformed AODV especially when congestion is too probable. Simulation results show higher PDR and lower delay for RPL in proportion to AODV. In addition RPL seems to be the better choice in scalability. AODV is heavily vulnerable from scalability in PDR and latency.

In [6] applicability of RPL in smart monitoring system to be used in smart grid is investigated. Results showed that RPL adapts efficiently to topology changes and rapidly makes routing knowledge, proving to be a good choice for smart grid. Nodes with higher hop count to root bear significantly more delivery delay when packet transmission rate increases.

J. Tripathi et al. [7] evaluated RPL performance simulating a real-life outdoor smart grid substation network. RPL performs in a satisfying level of delay and control overhead providing a rapid repair of corrupted links. Trickle timer manages control overhead efficiently lower in proportion to data packet. Using local repair performs much quicker in repairing local connection disruption than global repair mechanism.

In [8] main challenges in smart grid communication network design are discussed and different routing protocols for addressing the considered challenges are evaluated. Routing protocols are compared in terms of wireless or PLC communication, routing methodology and etc. In AODV further node to gateway suffers from a noticeable average end to end delay while it is ignorable in RPL. Distributed Autonomous Depth-first Routing (DADR) routing protocol is two slow in propagating routing table to the nodes which are not far away from gateway so DADR is not a suitable choice for smart grid.

E. Ancillotti et al. [9] studied RPL stability under several simulations in AMI networks. Results showed that RPL trend is to find dominant roots sine they are persistent routes.

## 3. RPL ROUTING PROTOCOL

Nodes in LLN network are resource constrained devices with small microprocessor and memory. They are usually battery powered and use low bandwidth and high loss rate radio communication. These specifications impress on the routing protocol to be used in these kinds of networks. LLN applications routing requirements are specified in [10-13]. IETF organized ROLL (Routing over Low power and Lossy networks) working group to specify a routing protocol for LLN. ROLL did analysis on set of routing protocols such as Open Shortest Path First (OSPF) , Intermediate System to Intermediate (IS-IS) and Optimized Link State Routing (OLSR) over LLN application and concluded that none of them can completely suit LLN routing requirements [4], so ROLL designed RPL (RFC 6550) [14].

ROLL was responsible for designing a new IPv6 routing protocol suitable for networks with large number of resource constrained devices satisfying different application areas such as home, building, industrial and urban automation.

RPL is configurable for the requirements of applications and the network it is decided to be used in. RPL main purpose is memory requirement minimization, supporting compressed routing information forwarding on restricted frame size link layers, providing simple routing and forwarding techniques consistent with simple constrained micro controllers and reducing routing and control overheads to optimize energy usage and bandwidth consumption [3].

RPL is an IPv6 distance vector routing protocol constructing Destination Oriented Directed Acyclic Graph (DODAG) from nodes. DODAG minimizes the path cost from a node to the root. RPL construct one or more DODAGs, and each node can attend at most in one DODAG. A network may exists with multiple topology each one created by a RPL instance. It is possible to have multiple RPL Instances defined by OFs to support different classes of traffic in a network. RPL Instance ID determines mainly the objective function that the DODAG is organized by. RPL uses ICMPv6 control messages to build the DODAG. DODAG Information Object (DIO) and DODAG Information Solicitation (DIS) are control messages transmitted in DODAG construction process. Each node calculates its rank by an Objective Function (OF). OF is an equation with parameters that are metric/constraint of link or node. Rank is a value determining the path cost to the root that a node provides. Rank decreases in the path toward the root and root node has the minimum rank value in the path. Each OF has an Objective Code Point (OCP) to be recognized by.

Root node start DODAG construction process by generating and sending DIO (DODAG Information Object) control packet to other nodes. DIO message contains DODAG ID, OCP, metrics and constraints (RFC 6551) [15] used for rank calculation. DODAG ID determines to which root the DAG is organized. OCP points the Objective Function defined for rank calculation. The nodes receiving DIO message compares the rank in DIO to its current parent rank and will select the DIO sender node as parent if the rank in DIO is less and If not, the node will add the DIO sender to its preferred parent list. Parent set holds a list of alternative minimum rank parent provisioning a path to root. Nodes replace the best node in parent list if current parent is not available. Each node calculates its rank base on the determined OF in DIO packet, updates the rank value in DIO packet and forwards it to other nodes. Figure 1 depicts the operation performed by receiving DIO. After that all nodes selected their parents a DAG is organized and nodes can transmit their packets toward the root through their parent. If a node does not receive DIO packet it will send DODAG Information Solicitation (DIS) control message to ask neighbors for transmitting DIO.

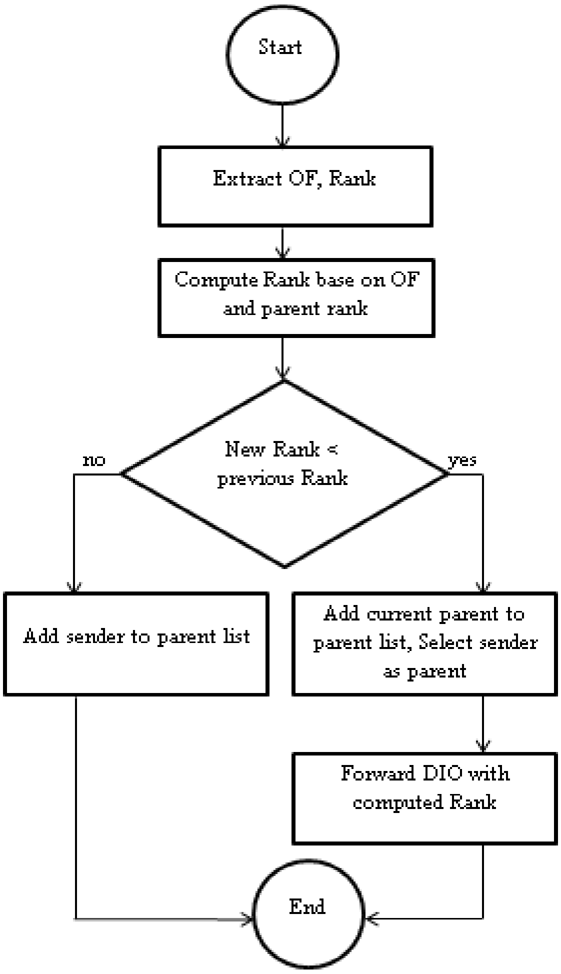

**Figure 1.** Operation performed after receiving a DIO

Root performs for a new version of DODAG construction by creating a DIO with increased amount of DODAG version number. Trickle timer controls the time of DIO transmission. When a node receives a DIO without any modification compared to previous DIO, increases the DIO counter and when the counter equals to a predefined threshold the counter is reset and trickle time is doubled. When Trickle timer reaches the value Imax or an event like a node fault happens, it is set to minimum default value Imin [16].

DODAG may be only responsible for upward traffic transition. Destination Advertisement Object (DAO) control message is used to define downward routes. After DODAG organization, nodes create and transmit DAO messages to introduce nodes that are reachable through them. DAO transition and process depends on DODAG mode of operation. In non-storing mode nodes send unicast DAO messages toward the root. In this case DAO contains information about sender node parent set too, so when root receives DAO messages from all the nodes along a path, can construct route toward the sender by extracting parent nodes recursively. In storing mode, nodes send unicast DAO messages to their parents and parents store reachable nodes through their children in routing table. Upon receiving a DAO, a node creates a DAO and sends to its parent to propagate routing information in network. DODAG can support only upward traffic or any mode of operation.

## 4. OBJECTIVE FUNCTION

In this paper we evaluate two OF implementation. One using Expected Transmission count (ETX) as link metric and the other using Hop Count (HC) in Rank calculation. In ETX based OF, nodes select the parent which has the lowest rank and ETX value. Each node calculates the ETX to candidate parents and selects the one with minimum overall ETX to the root. In HC based OF nodes try to have the minimum intermediate nodes to root.

ETX is the number of transmissions that a node must have to successfully deliver a packet to destination node. ETX can be calculated as below:

$$ETX = 1 / (DF*DR) \ [15] \qquad (1)$$

Where DF is the probability of receiving packet by the neighbor and DR is the probability of receiving acknowledgement successfully.

Node N calculates its rank as following:

$$R(N) = R(P) + ETX \qquad (2)$$

Where R (P) is the parent rank and ETX is the Expected transmission count to node P. after that node N calculated R(N), will select node P as parent if R(N) differs with the calculated previous one more than a defined threshold.

Hop count is the number of nodes that a packet must pass to reach the destination .In HC OF each node calculates its rank upon receiving the parent rank. Rank is the summation of parent rank and DEFAULT_MIN_HOP_RANK_INCREASE which is defined 256 in RFC (6550) [14]. So we define rank calculation in HC OF as following:

$$R(N) = R(P) + DEFAULT\_MIN\_HOP\_RANK\_INCREASE \qquad (3)$$

Where R (N) is Rank of the node and R (P) is rank of the node parent. Node N selects the parent node that minimizes R(N).

## 5. SIMULATION RESULTS

Contiki is an open source operating system for a network of resource constrained devices. Contiki provides multitasking and TCP/IP stack requiring only small amount of RAM and ROM. Contiki is capable to be run on different classes of hardware devices being constrained in terms of computational power, memory, network bandwidth and electricity power. COOJA is a contiki based network simulator allowing real hardware to be emulated. Extreme large scale wireless networks can be simulated by COOJA.

Simulation is used to evaluate the two OFs in AMI networks. The simulated AMI network is organized of 1000 nodes communicating with IEEE 802.15.4 radio. Contiki COOJA simulator is used to evaluate AMI network with one gateway and 1000 smart meters randomly dispersed in 300*300 m2 area. The nodes organize a DODAG sending their UDP CBR traffic toward the gateway. Smart meters send packets with 200 byte payload every 30 seconds toward the root. The scenario is simulated for 1300 seconds.

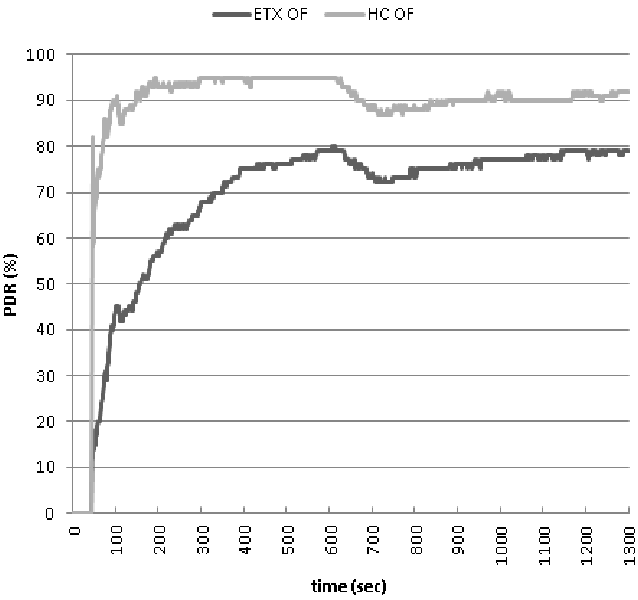

**Figure 2.** Packet Delivery Ratio VS. Time

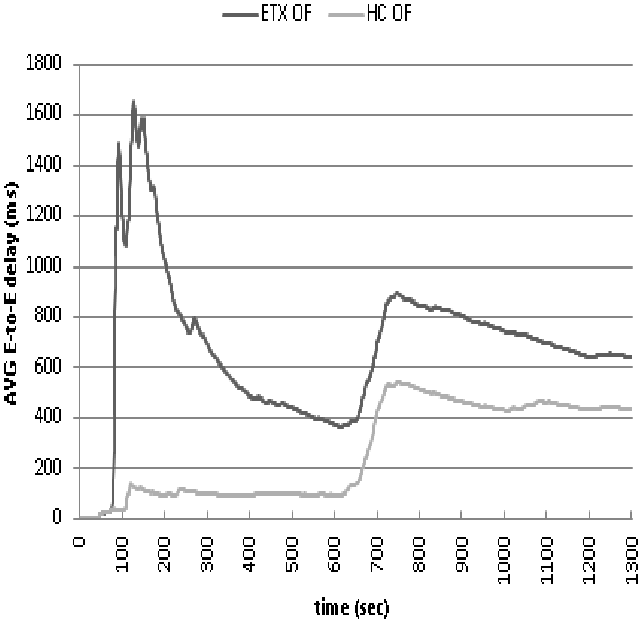

**Figure 3.** Average End to End Delay VS. Time

Packet delivery ratio is used as the metric to evaluate the OFs. PDR for the gateway is the ratio of number of packet received by gateway to the number of sent packets toward it. PDR is a value between zero and one. Higher PDR decreases retransmission more and more leading to less resource waste. PDR is computed as following:

$$\mathrm{PDR} = \frac{\text{NO.of received packets}}{\text{total of sent packets}} \tag{4}$$

Average end to end delay is the other criteria to evaluate OFs. Average E-to-E is the average of difference between gateway receiving time and node sending time for all received packets. It is calculated as below:

$$\mathrm{AVG\ \ E-to-E\ delay} = \sum_{i=1}^{n} \frac{packet\ received\ time - packet\ send\ time}{n}$$

Where n is the number of packets received by the gateway.

Figure 2 illustrates PDR versus simulation time. There is a great fluctuation at the beginning of the simulation because it has not finished the initialization phase. As the time passes nodes find better parents and paths to root so they update their parents resulting in PDR improvement. When each node selects the best possible node as parent, the PDR reaches its steady value with a little fluctuation. It is obvious that HC objective function outperforms ETX OF in case of PDR. HC OF delivers 90 percent of sent packets to the gateways while ETX OF delivers 80 percent of sent packets. Results are significantly different.

Average End to End delay against simulation time is depicted in Figure 3. ETX OF has more fluctuation before reaching steady state and this is because it needs time to optimize parent selection process. ETX OF has to evaluate and change more choices to select the best possible parent in proportion to HC OF. When simulation passes the initialization phase and reaches the steady state, the superiority of HC OF is clear. A packet sent base on HC OF reaches to gateway approximately 200 milliseconds sooner than a packet sent by ETX OF.

## 6. CONCLUSION

Smart grid communication is an emerging evolution to power grid systems. Cooperation between utility centers, customers, distribution station, different system and all entities in electricity generation, distribution and consumption is achieved by smart grid communication. AMI networks as a part of smart grid communication infrastructure require reliable and low latency communication. RPL is the preferred routing protocol for AMI networks providing the possibility to configure routing performance according to application requirements. RPL satisfies application requirements through Objective Function (OF) definition. RPL Objective Function calculates nodes Rank base on metrics and constraints that must be satisfied. Rank determines the path quality that a node provides toward the gateway. Nodes try to optimize the path quality toward the gateway by selecting the parent node with the minimum Rank. In this paper reliability and latency are critical factors supposed to be optimized by OFs. We define a merely hop count based version of OF0 to satisfy AMI network requirements and compare with ETX based OF. A large scale AMI network is simulated in contiki COOJA simulator to evaluate the two Objective Functions. Results show the superiority of the proposed Objective Function in packet delivery ratio and average end to end delay.

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