Mobility Supported Energy Efficient Routing Protocol for IoT based Healthcare Applications

Maja Lazarevska[†], Reza Farahbakhsh[*§], Nikesh Man Shakya[*‡], and Noël Crespi[*]

[*]Institut Mines-Télécom SudParis, CNRS UMR 5157, France. {reza.farahbakhsh, noel.crespi}@it-sudparis.eu

[§]TOTAL SA., Strategy & Innovation, EP/SG/ISB/STI/DataValo/Data Analytics Competence Center (DACC)

[†]Budapest University of Technology and Economics, {majalazarevska92@gmail.com}

[‡]ITRON, France. {shakya.nikeshman@gmail.com}

***Abstract*—Smart healthcare has been one of the major use cases of the Internet of Things (IoT) and Wireless sensor network (WSN) applications. WSN as a technique for sensing and acquiring data in IoT applications must work upon providing an efficient routing for proper data transfer. One of the fundamental concerns of the routing in WSNs is the energy consumption and the lifetime of sensors, since most of them rely on a battery and neither cable-powered nor frequent battery replacement or recharging are appealing options. The required routing technique must balance the goals: selecting the most reliable minimum energy path when all nodes have high energy and avoiding the low residual energy nodes while supporting mobility. This paper introduces a theoretical framework for RPL (Routing Protocol for Low power and Lossy Networks) based routing protocols whose aim is to provide energy efficiency while taking into account the mobility of sensor nodes in WSNs consisted of both static and mobile nodes. The simulation results indicate that the proposed routing model's Objective Function (OF) gives better performance in comparison to the default OFs in terms of duty cycle, energy consumption and total control overhead, while having a small degradation in the packet delivery ratio.**

***Index Terms*—eHealth, energy-aware protocols, IoT, mobility, Objective Function, RPL**

I. Introduction

Today, the Internet connects not only people, but also a variety of devices and gadgets. IoT is a trend in the next-generation technologies and is in the process of revolutionizing everyday physical objects to smart objects with the ability to sense, interact and react to the environment thanks to the combination of Internet standards, protocols and other emerging technologies [1]. The technological breakthrough of the IoT allows benefits in many application areas, such as: smart home, medicine and healthcare, logistics and transport, agriculture, smart mobility and many more [2].

Most importantly, IoT offers great promises in healthcare, as the eHealth aims to provide complete ubiquitous monitoring of the patient anytime and anywhere and transmission of personal examination data to the healthcare center via Internet or WSN [3]. The IoT enabled eHealth services are consisted of three main layers: sensing layer, data transmission layer and processing and analysing layer. The sensing, processing, computation and wireless communication are performed by small sized nodes included in a WSN. In comparison to traditional wireless networks, the sensor nodes of WSNs are limited in power, computational capacity and memory [4]. Thus, designing routing protocols for WSN becomes a challenge influenced by hardware restrictions, energy consumption and network topology. The energy management in WSNs is important due to the limited energy availability of the wireless devices. Routing protocols are able to make smart decisions that increase the lifetime of the WSN by estimating the energy consumption of the sensor nodes. Recent advances in WSNs have led to many new routing protocols specifically designed for WSNs where mobility and energy awareness are an essential consideration [5]. The contributions of this paper are as follows: referencing the shortcomings of the existing routing protocols in biomedical WSNs in context of energy efficiency and mobility; study of the RPL algorithm in Contiki Operation System (OS); specifying the application requirements and network limitations; identification of relevant link and network metrics; providing a novel algorithm as a combination of the relevant routing metrics; evaluation of the result with appropriate evaluation parameters; comparison of the novel optimized RPL OF with the state of art OF (MRHOF with ETX metric).

II. Related Work

A. Routing protocols in IoT eHealth domain

Since biomedical WSNs usually have lower processing and radio power, transmission speed, memory and energy supply than the WSNs in other domains, they belong to the group of Low-power and Lossy Networks-LLNs (RFC 7228). One of the major challenges in LLNs includes safe and stable routing of data without influencing the quality of the communication links. Hence, the modeling and designing of an energy efficient IoT-based wireless system becomes a challenging task.

For the purposes of this study, RPL is used as a specification on how to build a Destination Directed Acyclic Graph (DODAG) using an OF. The OF is consisted as a logic that incorporates set of metrics that allow optimization of the RPL path selection. The RPL protocol, designed by IETF ROLL working group, is a type of Proactive Distance Vector Algorithm (RFC 6550) used in the domain of IoT healthcare. The sensor nodes running RPL might use number of metrics to describe a link or a node and all of these metrics, placed in one or more Metric Containers (MCs), available for route selection. The two default RPL OFs are Objective Function Zero (OF0) and Minimum Rank with Hysteresis

Objective Function (MRHOF). The OF0 is constructed with function that holds the hop count information, while MRHOF is using Expected Transmission Count (ETX) as a default metric that selects minimum cost path, while using hysteresis for path calculation. Previous studies show MRHOF provides better performance than OF0 in term of energy consumption, reliability and stability [6]. Despite the exceptional results of MRHOF, its main use is to build topologies where the bottleneck nodes can be deteriorated due to the excessive unbalanced traffic load they experience and thus disconnection or damage of the network is probable. Following the need of new OF beneficial to energy consumption and network lifetime in mobile networks.

B. Energy optimization in IoT based routing protocols

Using a new RPL metric in the OF in LLNs, where the rank calculation formula operates using other metric rather than the ETX, such as PER HOP-ETX [7], node's remaining energy (RE) [8] or RSSI (Received Signal Strength Indicator) [9], can be advantageous. The system implementer is free to decide whether to use one or multiple routing metrics, as well as the way these metrics would be combined. The lexical approach is based on having two or more conditions for the composite metric comparison. The additive metric composition, includes metric calculation based on composition function defined in the OF (ROLL Standard).

C. Mobility support in energy-aware routing protocols

The frequent topology change of the nodes might result in deterioration in the quality of the links, packet delivery delay, packet collision or other inconsistencies [5]. Thus, the mobility models play a key role in the performance estimation of the routing protocols in WSN. A geographic routing protocol called EAGRP which takes into consideration both nodes location local information and energy consumption for making routing decisions is proposed [10]. Improvement of the Packet Delivery Ratio (PDR), end-to-end delay and energy consumption while maintaining low packet overhead and loop-avoidance in the dynamic RPL networks was developed in [11], while the slope of the throughput as a metric to predict the most likely breakable link is shown in [12].

This paper presents a novel OF that provides a reliable and energy efficient best parent selection in mobile environment. In order to prove its efficiency, a comparison between the state-of-art MRHOF and the presented OF is given. Moreover, in addition to the energy efficiency of the novel OF, its main contributon is represented with its implementation in mobile nodes.

III. Proposed Model

The proposed scenario is motivated by the fact that even though the physical mobility appoint to network dynamics, it is a major source of inconsistency and high energy consumption in the network. ContikiRPL is a real world implementation of RPL developed under the Contiki OS with simple programming interface for designing and evaluating OFs. The following paragraph presents a model for designing an OF using additive metric approach consisted of multiple metrics, considering three main issues in LLN routing (reliability, energy consumption and mobility). To demonstrate the hypothesis, a basic scenario, presented as hospital environment with random topology consisted of one static sink node placed centrally at the deployment area (data collector) and various static (medical instruments) and mobile sensor nodes (wearable or implantable sensor nodes on the body of the patients) with mesh topology, is evaluated.

A. Metrics definition

The choice of the metrics used in the OF plays an enormous role in the performance analysis. The selection of basic and derived metrics used for designing an efficient composite metric must be carefully chosen since combining routing metrics of different types may lead to routing loops or selection of non-optimal paths. Two general approaches for metrics combination are the lexical and additive approach. For the proposed case where the three characteristics must be considered in a balanced manner, the additive composition approach is more advantageous. The newly-proposed OF has a task to specify how the network nodes form paths to route the data packets through the network in an efficient and optimal manner. Furthermore, the new OF (so called NEWOF) defines three metrics for best path calculations: link Expected Transmission Count (ETX), Remaining Energy (RE) of the node and RSSI (Received Signal Strength Indicator). ETX represents the reliability through the total number of link layer transmssions to make a successful transmission. The RE of the node after a transmission is given as the difference between the initial energy of the node and the consumed energy. Whereas the RSSI is a signal strength in a wireless network indicating the power present in a received radio signal, while link symmetry being assumed. The RSSI changes as the location of the sensor nodes change, thus representing the dynamics of the sensor nodes. The best parent (node that should be optimally selected and through which the data routing would be performed) selection is performed by comparison of the path costs of the potential parents. The path cost is calculated as the sum of the rank and the link cost where the link cost represents an additive function of the metrics (ETX, RE, RSSI) using different weight values for each of them. The rank represents a monotonously increasing function used for avoiding loops and choosing non-optimal paths for routing. The characteristics (domain, unit, representation) of the used metrics in the NEWOF are represented in Table I. Moreover their derived metrics are being modified in such a way to follow the same order, domain and relation, which is a requirement for the combination of metrics used in OFs.

B. Objective Function Algorithm

After defining the desired metrics in the MCs of the DODAG Information Object (DIO) message, they are advertised and can be used for the path selection process. The path selection process consists of link cost calculation between the parent node j and node i, using additive metric approach,

TABLE I: Used metrics for the NEWOF

Metric	**ETX** (Expected Transmission Count)	**RE** (Remaining Energy)	**RSSI** (Received Signal Strength Indicator)
Domain of native metric	[1,512]*128	[0,1] or [0, max RE]	[0,255]
Composition Metrics	1/linkETX	RE/maxRE	RSSI/maxRSSI
Composition metric	(0,1]	[0,1]	(0,1]
Unit	Unitless	% or mJ	dBm
Representing	Reliability (link quality)	Energy	Mobility

whose formula depends on the values of the link ETX, node RE and RSSI, as shown in Equation 1. The link cost values are in the domain (0,1], same as the domain of each modified metric in the additive formula, the order relation is "<" and the aggregation rule is additive.

$$\mathrm{LinkCost_{i-j}} = \mathrm{a}\frac{1}{\mathrm{linkETX_{i-j}}} + \mathrm{b}\frac{\mathrm{RE}}{\mathrm{max(RE)_j}} - \mathrm{c}\frac{\mathrm{RSSI}}{\mathrm{max(RSSI)_i}} \tag{1}$$

where a, b and c are the weight constants set to 0.2, 0.5 and 0.3, respectively. These balancing values are distinguished experimentally as the most suitable weights for the trade-off between ETX, RE and RSSI. For the purposes of the path cost calculation formula the link cost values must be normalized in order to set the $<$ order relation to each metric, as implemented in Equation 2.

$$\mathrm{CorrectedLinkCost_{i-j}} = 1 - \mathrm{LinkCost_{i-j}} \tag{2}$$

Knowing these values for each link, the path cost can be calculated as sum of the rank and the corrected link cost, as shown in Equation 3, whereas the rank is an iterative monotonously increasing function calculated as presented at Equation 4. The value of the rank at the root is always 0, where j is the parent node.

$$\mathrm{PathCost_{i-j}} = \mathrm{Rank_j} + \mathrm{CorrectedLinkCost_{i-j}} \tag{3}$$

$$\mathrm{Rank_i} = \mathrm{PathCost_{i-j}} \tag{4}$$

Subsequently, the next node that becomes the parent node in the hierarchy, takes the value presented in Equation 4, as its value of the rank, as $Rank_j = Rank_i$.

Finally, the parent is selected through comparison between the path cost of the preferred parent and the path cost of the potential parent. The parent with the lower path cost is selected as an optimal parent. The Algorithm 1 shows the pseudocode of the proposed OF, in terms of calculations for link cost, path cost, corrected path cost and best parent selection. In an ideal case, the best parent would be a parent with highest RE, lowest ETX and higher RSSI. Before the implementation, several straight forward observations were made. It was expected that as the number of nodes increases, the power consumption would increase too. Also, if the sensor node is far away from the sink or out of the transmission range, the number of hops through which the data is routed is higher, the ETX is higher and that withdraws higher energy consumption. The mobility

Algorithm 1 Algorithm for energy efficient and reliable routing protocol supporting mobility

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procedure OBJECTIVE FUNCTION(ETX, RE, RSSI)  ▷
Root broadcast DIO message
DIO message being processed by the node

    while Sensor_N odes_R eceive_D IO_M essages do
        Node updates values for ETX,RE and RSSI
        Link cost calculation
        Corrected Link Cost
        Path cost calculation
        Best parent selection
        if No Preferred Parent then
            Return New Parent
        elsePreferred parent exist
            if NewParent.PathCost < PreferredParent.PathCost then
                PreferredParent.PathCost = NewParent.PathCost
                return PreferredParent=NewParent
            end if
            Return Preferred Parent
        end if
    end while
end procedure
```

support in network models may lead to excessive packet loss and delays, in addition to the higher power consumption. Given the fact that the NEWOF considers the mobility as part of the metric composition, it should solve these challenges, allow maximization of the network lifetime and lower power consumption and enhance the stability of the network.

IV. Equipment and methods

A. Equipment

Contiki RPL is an implementation of the RPL using two basic OFs (OF0 and MRHOF). Its behavior is being evaluated using the Contiki OS and Cooja simulator [13]. In this study, the Tmote Sky platform that presents an ultra low power light weight wireless module, offering high reliability, performance and ease of deployment, is used. At the end, the simulation results from the Cooja simulator is analysed and presented by using Matlab.

B. Methods

1) Network model: The WSN used in the healthcare services includes sensors placed on or inside the human body. Furthermore, these acquired information are transmitted to a coordination node (sink), whose task is to gather all the data from the sensor nodes and to provide that data to the healthcare center through network or cloud services.

2) Energy model: The energy model is implemented using the default ContikiOS tool-PowerTracker and Energest model implemented in the C file of the OF. The PowerTracker is an online real-time radio duty cycle monitoring tool, whose output is a measure of the average simulated radio duty cycles of the transmission (Tx) and reception (Rx) of data of each node in percentages (%). The transmission and listen times for

TABLE II: Simulation Parameters

Network Parameters	
Deployment area	500m x 500m
Interference range	250m
Transmission range	100m
Number of sensor nodes	10,20,30,50,80,100
Number of sink nodes	1
Avg. capacity of an AA battery	2500 mAh
Network layer	IPv6 with 6LowPAN
Transport layer	UDP
Frequency	2.4 GHz
Receive Sensitivity	-90 dBm
Transmission Power	-25 dBm
Application Properties	
Task type	Time Driven
Data traffic Rate	250 Kbps
Data length	30 bytes per packet
Speed	No limit speed
Simulation Properties	
Simulation Time	600s
Advanced Settings	UDGM (random seed)
Type of radio	CC2420
MPU	MSP430

each sensor node can be calculated according to the Equation 5 and Equation 6, respectively.

$$\mathrm{Time\_Rx} = \frac{\mathrm{Rx\%}}{100} \cdot \mathrm{Simulation\_Time} \tag{5}$$

$$\mathrm{Time\_Tx} = \frac{\mathrm{Tx\%}}{100} \cdot \mathrm{Simulation\_Time} \tag{6}$$

Furthermore, using the given formulas, the energy consumption for each node and for the whole network can be estimated. The Equation 7, presents the Energy Linear Model, where the energy is represented through the power P (voltage V and current I) and the time spent in particular state t. The values for the voltage and the transmission and reception current are predefined as 3 Volts, 8.5mA and 19.7mA, respectively (according to CC2420 datasheet for biomedical BAN networks), whereas the simulation time for the transmission and reception is calculated via the radio duty cycle as already shown in the Equation 5 and Equation 6.

$$\mathrm{E} = \mathrm{P} \cdot \mathrm{t} = \mathrm{V} \cdot \mathrm{I} \cdot \mathrm{t} \tag{7}$$

$$\mathrm{E\_rx} = \mathrm{P\_rx} \cdot \mathrm{Time\_rx} = \mathrm{V} \cdot \mathrm{I\_rx} \cdot \mathrm{Time\_rx} \tag{8}$$

$$\mathrm{E\_tx} = \mathrm{P\_tx} \cdot \mathrm{Time\_tx} = \mathrm{V} \cdot \mathrm{I\_tx} \cdot \mathrm{Time\_tx} \tag{9}$$

$$\mathrm{E\_total} = \mathrm{E\_tx} + \mathrm{E\_rx} + \mathrm{E\_cpu} + \mathrm{E\_lpm} \tag{10}$$

The total energy consumption is estimated as the sum of the independently estimated energy consumptions for Tx, Rx, CPU (Central processing unit) and LPM (Low Power CPU Model), as given in Equation 10. However, since the values of the E_{cpu} and E_{lpm} are relatively small in comparison to the E_{tx} and E_{rx} (Equations 8 and Equation 9) they could easily be neglected in the final formula for total average energy consumption. To that end, the total average energy consumption can be estimated as given in $E\_total = E\_tx + E\_rx$.

3) Mobility model: Furthermore, a mobility plugin was integrated in the Cooja simulator to support the mobility of the nodes. It uses a data file for the movements of the nodes in the system with the following format: #node time(s) x y.

V. Implementation and Simulation Results

A. Implementation and Simulation setup

Designing and testing routing protocols in reality can consume a lot of time and cost a lot of money. Even though there is no 100% efficient simulator, using certified and known network simulators is a good way to test and evaluate a new protocol design. As presented in Section III, the evaluation of the proposed RPL model was performed in ContikiOS with Cooja simulator. For the purposes of this study, the RPL performance was analyzed using Matlab. The OF performance in the proposed model was compared with the default MRHOF with ETX metric and several conclusions were perceived.

1) Scenario: Simulations were carried out to validate the proposed OF performance. Due to the dynamic nature of the mobile sensor nodes, an average evaluation was necessary, thus it was required that each simulation is performed with at least two iterations. The used parameters for the simulation are shown in Table II, selected to match the characteristics of recent innovative deployments of IoT technology in biomedical applications according to the parameters given in [14]. The simulation duration was set to 10 minutes per simulation and after that time the results from the Powertracker tool and log files were obtained and ready for analyses.

2) Evaluation metrics: For the analysis purposes, the Powertracker tool in Cooja ContikiOS in addition to the raw logging files for statistical analysis were used to process UDP (User Datagram Protocol) data packets at the root node and evaluate the performance parameters. The parameters used to evaluate the performance of the NEWOF are: Duty Cycle, Average Energy Consumption, Network Lifetime, Packet Delivery Reception and Average Total Control Traffic Overhead.

B. Results

In this subsection, the results of the performance of the NEWOF are presented and then discussed and compared with the previous studies of the default MRHOF. Figure 1 gives comparison of the average total traffic overhead for different number of nodes for MRHOF and NEWOF. NEWOF gives an improvement on it in comparison to MRHOF as a result of the changes made in the format of the DIO message that involved using two MCs and three metrics for path selection. However, in both the NEWOF and MRHOF the increase of the total traffic overhead as the number of nodes increases is an inevitable result. Figure 2 shows the packet delivery ratio (PDR) of RPL compared to the network size. As expected, there is a decrease of the PDR as the number of nodes increases. When compared with the MRHOF, it is noticeable that the NEWOF has a very low compromise in the PDR with loss of 3%. Figure 3 gives the transmission (Tx) and reception (Rx) duty cycles for MRHOF and NEWOF, whose influence is noted in Figure 4, where the best performance

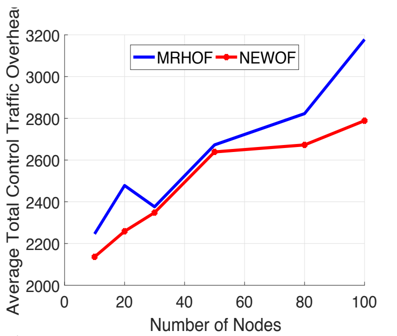

Fig. 1: Average Total control traffic overhead per #Nodes

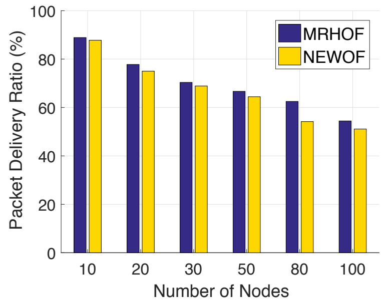

Fig. 2: Average Packet Delivery Ratio per #Nodes

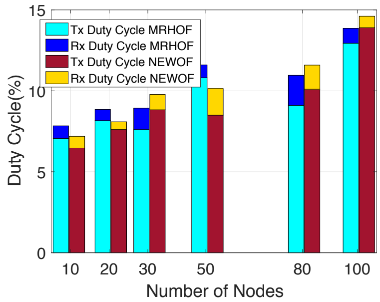

Fig. 3: Duty Cycle per #Nodes

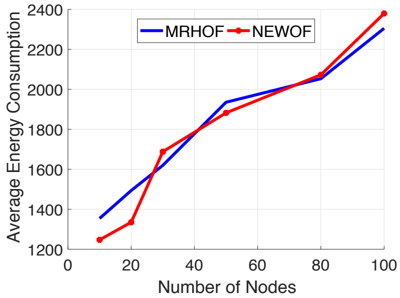

Fig. 4: Energy Consumption per #Nodes

TABLE III: Network lifetime results

OF	**Network lifetime (sec.)**
MRHOF (default)	4980
NewOF (no mobility)	5005
NewOF (mobility)	3886

energy consumption per number of nodes is presented. As the number of nodes increase, the percentages of the duty cycles of MRHOF and NEWOF increase too. The average values of the energy give gain of 1,45 % in range of 0 to 100mJ for the energy consumption of NEWOF. Accordingly, as the number of nodes increase so does the energy consumption, since the total energy consumption is a sum of all the energy consumptions in the system. The network lifetime is the time until the first node exhaustion. The NEWOF and MRHOF were implemented in two basic scenarios of five nodes with success ratio of 80%/80%, one using the mobility plugin and other without. The results proved that NEWOF provides better results that MRHOF when used with static nodes. However when the mobility plugin was implemented the model showed loss of approximately 20 %, as given in Table III. Finally, the summary of results is presented in Table IV. To conclude, the NEWOF used in mobile WSNs provides improvement in the default MRHOF with gain in aspect of the total control overhead and energy consumption, while showing low compromise on the PDR.

TABLE IV: Summary of the simulation results and statistics

Parameter	**MRHOF**	**NEWOF**	**Gain (%)**
Total Overhead	2628	2473	5.8
Packet Delivery Ratio(%)	70.1	66.89	-3.21
Energy Consumption(mJ)	1793	1767	1.45

VI. Conclusion

In this paper, the experiment was simulated on the Contiki OS using Cooja simulator. The simulation file was composed of N mobile nodes and one static sink node. In conclusion, the novel OF provided improvement in the state-of-art OF used in low power and lossy networks in the smart healthcare in terms of total energy consumption and total control traffic overhead, with small degradation in the PDR and with that proved its efficiency. In addition, the contribution of the novel OF is focused on adding the energy efficiency and mobility constrains to the default OF. However the design of an efficient OF is still an open research issue.

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