Mobility Supported Energy Efficient Routing Protocol for Healthcare Applications

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***Abstract*—Smart healthcare has been one of the major use cases of the Internet of Things (IoT) and Wireless sensor network (WSN) applications. Improving the efficiency of the IoT healthcare and biomedical applications has become one of the most challenging goals of today. WSN as a technique for sensing and acquiring data in IoT applications must work upon providing an efficient routing in order to transfer data promptly and properly. One of the most fundamental concerns in the routing in WSNs is the energy consumption and the lifetime of the sensors, since most of them rely on a battery. Neither cable-powered nor frequent battery replacement or rechargement are appealing options in these applications. 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 and routing algorithm for RPL (Routing Protocol for Low power and Lossy Networks) based routing protocols whose main aim is to provide energy efficiency while taking into account the mobility of sensor nodes in WSNs consisted of both static and mobile nodes, while maintaining acceptable reliability. The simulation results indicate that the proposed routing model's Objective Function (OF) gives better performance in comparison to the default Minimum Rank with Hysteresis Objective Function (MRHOF) 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. The phenomenon IoT is a megatrend 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, communication protocols and other emerging technologies [1], [2]. The technological breakthrough of the IoT allows benefits in many application areas, such as: Smart grid, Smart home, public safety and environmental monitoring, independent living, medicine and healthcare, logistics and transport, agriculture and breeding, industrial processing, smart mobility and many more [3].

Most importantly, IoT offers great promise in the field of healthcare. The electronic Health (eHealth) represents an emerging field whose aim is to provide and deliver better connected and coordinated healthcare, support decision making and connecting information through the Internet or related technologies. The novel platform eHealth would provide complete ubiquitous monitoring of the patient anytime and anywhere and transmission of personal examination data to the healthcare center via the Internet or wireless application system [4]. 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 usually performed by small sized nodes included in a WSN. In comparison to the traditional wireless networks, the sensor nodes of WSNs are limited in power, computational capacity and memory [5], [6]. Thus, designing routing protocols for WSN becomes a challenge influenced by hardware restrictions, energy consumption and network topology [7]. The energy management in WSNs is of paramount importance 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 [8]. 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 design of RPL algorithm in Contiki Operationg System (OS); specifying the application requirements and network limitations; identification of the relevant link and network metrics demonstrating link quality, energy consumption and mobility in the OF; providing a novel algorithm as a combination of the relevant routing metrics; evaluation the result with appropriate network evaluation parameters; comparison of the novel optimized RPL OF with the state of art OF (MRHOF with ETX metric).

The rest of the paper is organized as follows. In Section II is presented the related work on energy aware and lifetime maximizing routing techniques in static and mobile sensors. The illustration of the proposed model is given in Section III, whereas Section IV describes the equipment and methods suitable for the model considering the problem of routing in biomedical WSNs. Experimental simulations were carried out and the results of the simulations are presented and compared with existing protocols as discussed in Section V. Finally, Section VI presents a conclusion of the work and states the open challenges for future research which may be helpful to the researchers in forthcoming time.

II. RELATED WORK

A. Routing protocols in IoT eHealth domain

Since biomedical WSNs (wearable and more especially implanted ones) usually have much 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, while using the constrained resources like energy. Hence, the modeling and designing of an energy efficient IoT-based wireless system becomes a challenging task.

Some of the frequently used types of routing protocols in eHealth IoT are the following: cross-layer, thermal-aware, link-aware, cluster or tree based, opportunistic, MAC and distance-vector protocols. Distance vector algorithms only have knowledge of the routing tables of their neighbors and due to that, they do not require high power and memory. Therefore, they are preferred in context of cost of implementation and support since they are less expensive than other types of routing protocols. The RPL protocol, designed by IETF Routing Over Low power and Lossy network (ROLL) working group, is a type of Proactive Distance Vector Algorithm (RFC 6550) usually used in the domain of IoT healthcare. Moreover, RPL is used as a specification on how to build a Destination Directed Acyclic Graph (DODAG) using an Objective Function (OF). The OF is consisted of a logic that incorporates set of metrics that allow optimization of the RPL path selection. 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), are available for route selection. The two default RPL OFs are Objective Function Zero (OF0) and The Minimum Rank with Hysteresis Objective Function (MRHOF). The OF0 is constructed with function that holds the hop count information. MRHOF, on the other side, is using Expected Transmission Count (ETX) as a default metric that selects minimum cost path, while using hysteresis for path calculation. Researches based on simulations and analysis have concluded that MRHOF gives better network performance than OF0 in aspects of energy consumption, reliability and stability [9], [10]. 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. Consequently, disconnection or damage of the network is probable considering the fragility of the preferred routing nodes that require much higher energy drain than the other candidate parent nodes [11]. Thus, a novel OF beneficial to the energy consumption and network lifetime in mobile networks must be proposed.

B. Energy optimization in IoT based routing protocols

The following paragraph gives a more detailed observation of existing routing protocols in respect to energy optimization. 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 the number of children [11], PER HOP-ETX [12], node's remaining energy (RE) [13], [14] or RSSI (Received Signal Strength Indicator) [15], [16], 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 [17]. Thus, other proposed solutions cover the usage of additive or lexical combinations. The lexical approach is based on having two or more conditions for the composite metric comparison. The additive metric composition, on the other hand, includes metric calculation based on composition function defined in the OF (ROLL Standard). Combining more than one routing metrics is applicable as suggested by [18]–[20] where novel energy-aware OFs that use a lexical combination of the ETX and RE metrics in the best path selection function are proposed.

C. Mobility support in energy-aware routing protocols

In the sequel, an overview of the protocols which are capable to support the mobility of nodes in the context of energy-aware routing in WSNs will be given. 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 [8]. Thus, the mobility models play a key role in the performance estimation of the routing protocols in WSN. [21] provides an analysis that shows that communication towards mobile nodes is not feasible in standard RPL protocols due to slow parent switching mechanism. A geographic routing protocol called EAGRP which takes into consideration both nodes location local information and energy consumption for making routing decisions is proposed [22]. 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 with the OF proposed in [23], while the slope of the throughput as a metric in order to predict the most likely breakable link is shown in [24].

In response to the mentioned challenges, 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 addtition to the energy efficiency of the novel OF, its main contributon ir 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 presents the first real world implementation of RPL developed under the Contiki Operating System with its main feature, simple programming interface for designing and evaluating OFs. The following paragraph presents a model whose approach includes 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 representing the data collector and various static and mobile sensor nodes, is evaluated. The static sensor nodes represent the static devices in the hospital (medical instruments), whereas the mobile nodes include the wearable or implantable sensor nodes on the body of the patients. Additionally, the preferred topology is mesh topology, whose advantages are: self-healing, higher data rates, higher scalability and interoperability [25].

A. Metrics definition

The choice of the metrics used in the OF plays an enormous role in the performance analysis of the routing protocol. The selection of basic and derived metrics used for designing an efficient composite metric used in the OF must be carefully chosen since combining routing metrics of different types may lead to routing loops or selection of non-optimal paths. Lexical and additive approach are the two general approaches for metric combination. Even though more demanding, the additive approach is more advantageous since it offers the possibility to satisfy the QoS requirements of the network according to the user demand. Such flexibility is not possible in lexical approach, since the metric used first is dominating over the second metric [26]. Thus, for the proposed case where the three characteristics must be considered in a more balanced manner, the utilization of the additive composition approach is 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. The choice of the composition metrics contained in the additive metric was made according to the system requirements. Furthermore, the new OF (so called NEWOF) defines three metrics for best path calculations, according to the network requirements: 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 tranmssions 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 selection is performed by comparison of the path costs of the potential parents. Moreover, the term parent describes the node that should be optimally selected and through which the data routing would be performed. 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 mentioned metrics (ETX, RE, RSSI) using different weight values for each of them. The rank, on the other side, 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 [26].

TABLE I: Used metrics for the NEWOF

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

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, whose formula depends on the values of the link ETX, node RE and RSSI, as shown in Equation III-B. 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 as the most suitable weights for the trade-off between ETX, RE and RSSI, taking the RE of the node as the paramount metric. According to the requirements, the sum of all the weight values in the formula must be equal to 1 (a+b+c=1). The weights of each metrics are set so that the resulting value of the link cost provides an optimal link selection. The values of the maximum RE and maximum RSSI are set according to the specifications for a possible real life scenario in a healthcare application to 10800 mJ and 255 dBm, respectively. 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 III-B.

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

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.

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

, where j is the parent node.

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

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 shown in Equation 5.

$$\mathrm{Rank_j} = \mathrm{Rank_i} \tag{5}$$

Finally, the parent is selected through comparison between the path cost of the preferred parent and the path cost of the potential parent and 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 and simulation, 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 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 is expected that the new algorithm will solve these challenges, allow maximization of the network lifetime and lower power consumption and enhance the stability of the network.

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
```

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 trffic 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

IV. EQUIPMENT AND METHODS

A. Equipment

Contiki RPL is an implementation of the RPL protocol using two basic objective functions (OF0 and MRHOF). Its behavior is being evaluated using the Contiki Operating System and Cooja simulator [27]–[29]. For the purposes of the 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 (Tmote Sky Datasheet).

At the end, the simulation results from the Cooja simulator were analysed and presented using Matlab.

B. Methods

1) Network model: Usage of WSNs in IoT technologies is one of the preferred technologies for collecting and processing data from vital parameters. Their convenience and mobility capabilities make them a good candidate for providing a reliable, effective and favorable technology for eHealth applications. The WSN used in the healthcare services includes several sensors placed on or inside the human body in order to collect its vital parameters. 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 using communication protocols.

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 (%). With the values for the transmission and listening average duty cycles and knowing the run simulation time, the transmission and listen times for each sensor node can be calculated according to the Equation 6 and Equation 7, respectively.

$$\text{Time\_Rx} = \frac{\text{Rx\%}}{100} \cdot \text{Simulation\_Time} \tag{6}$$

$$\text{Time\_Tx} = \frac{\text{Tx\%}}{100} \cdot \text{Simulation\_Time} \tag{7}$$

Furthermore, using the given formulas, the energy consumption for each node and for the whole network can be estimated. The Equation 8, 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 6 and Equation 7.

$$\text{E} = \text{P} \cdot \text{t} = \text{V} \cdot \text{T} \cdot \text{t} \tag{8}$$

$$\text{E\_rx} = \text{P\_rx} \cdot \text{Time\_rx} = \text{V} \cdot \text{I\_rx} \cdot \text{Time\_Rx} \tag{9}$$

$$\text{E\_tx} = \text{P\_tx} \cdot \text{Time\_tx} = \text{V} \cdot \text{I\_tx} \cdot \text{Time\_Tx} \tag{10}$$

$$\text{E\_total} = \text{E\_tx} + \text{E\_rx} + \text{E\_cpu} + \text{E\_lpm} \tag{11}$$

The total energy consumption can be estimated with 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 11. However, given the assumption and as presented in the Collect view tool in Cooja, the values of the E_{cpu} and E_{lpm} are relatively small in comparison to the E_{tx} and E_{rx} (Equations 9 and Equation 10), so 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 Equation 12:

$$\text{E\_total} = \text{E\_tx} + \text{E\_rx} \tag{12}$$

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. The evaluation method is a method commonly used to compare and evaluate routing protocols. For the purposes of this study, the RPL performance was analyzed using Matlab. The OF performance in the proposed model was compared with one of the default objective functions in Cooja-MRHOF with ETX metric and several conclusions were perceived. The used parameters for the simulation experiment are shown in Table II, selected in such a way to match the characteristics of recent innovative deployments of IoT technology in biomedical applications according to the parameters given in the CC2420 RF Chip Design Guidelines in [26].

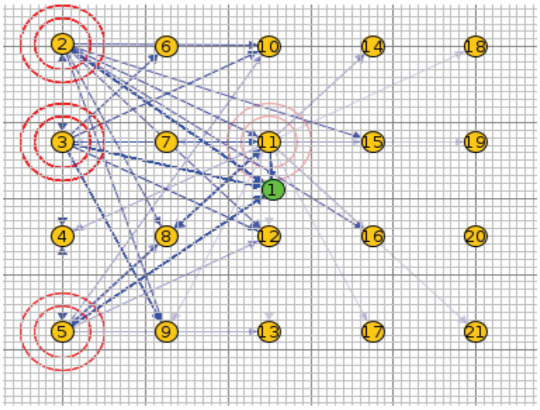

Fig. 1: Experimental testbed for linear topology

1) Scenario: The testing of the performance metrics was completed using a hospital scenario, where the WSN includes one sink node and multiple mixed sensor nodes. Simulations were carried out to validate the proposed OF performance. The excessive experiments were performed out using randomized mesh network topology. 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 scenario was deployed in 500m x 500m square area, with 10, 20, 30, 50, 80 and 100 sensor mobile nodes and one static sink node located at the center of the deployment area. After the default network setup time of 60s, each sensor node periodically sends data to the sink using UDP as the transport layer with a Tx/Rx success ratio that was changed accordingly per simulation(80%/80%, 80%/60%, 80%/40%, 80%/20%). The interference and transmission distances were set to 250m and 100m, respectively. 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. Figure 1 represent a testbed of the simulation scenario with 20 sensor nodes and one sink node sorted in linear topology. In addition to the linear topology, grid topology was used for the simulations.

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. A complete energy consumption analysis is necessary for a reliable network lifetime prediction. 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.

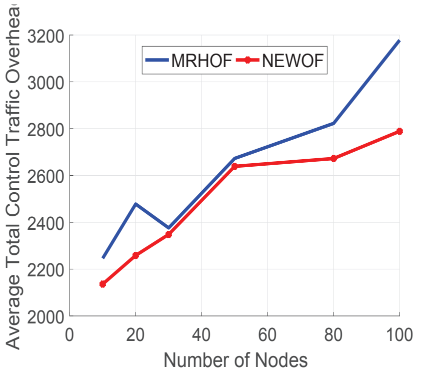

Fig. 2: Average Total control traffic overhead per #Nodes

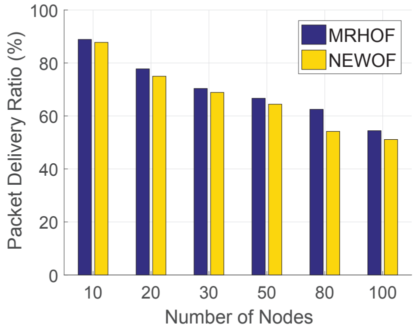

Fig. 3: Average Packet Delivery Ratio per #Nodes

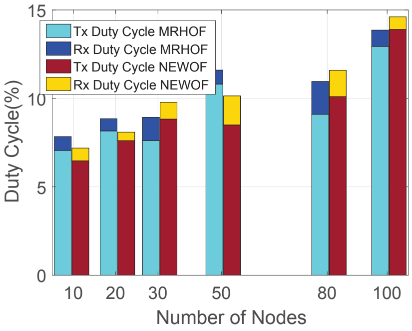

Fig. 4: Duty Cycle per #Nodes

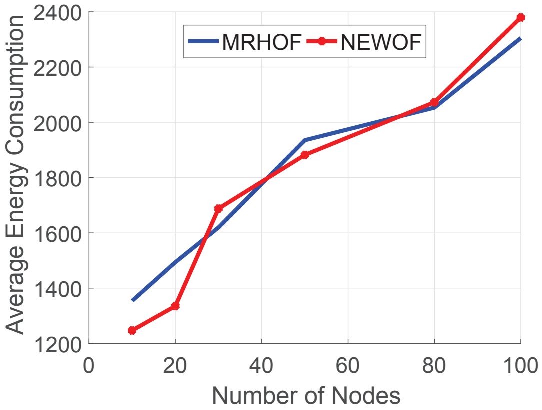

Fig. 5: Energy Consumption per #Nodes

TABLE III: Network lifetime results

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

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

B. *Results*

In this subsection, the results of the performance of the NEWOF are presented and subsequently discussed and compared with the previous studies of the default MRHOF. For each simulated scenario of different network size and different transmission/reception success ratio undergoing different randomized mobility values, two simulations were applied repeatedly so that the final results are computed as most accurate average values. Figure 2 gives comparison of the average total traffic overhead for different number of nodes for the default MRHOF and the NEWOF. It can be noted that the NEWOF gives an improvement on the total control overhead in comparison to MRHOF. This improvement might be the 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 3 shows the packet delivery ratio (PDR) of RPL compared to the network size. As expected, there is a significant 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 and loss of 3%. Figure 4 gives the transmission (Tx) and reception (Rx) duty cycles for MRHOF and NEWOF, whose influence is noted in Figure 5, where the best performance 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. As it can be visualized from the graph, the average values of the energy give significant 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 being calculated as 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 the results is presented in Table IV providing a significant value to the research in mobile WSNs. To conclude, the NEWOF 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.

VI. CONCLUSION AND FUTURE PLANS

The experiment was simulated on the Contiki OS using Cooja simulator. The simulation file was composed of N mobile nodes and one centraly located static sink node. Finally, the simulated results were documented and a Matlab code was used to analyse logs generated by nodes after simulation time in order to determine if the mobile nodes were able to route packets through the most optimal, reliable and energy efficient path. In conclusion, the novel OF provided improvement in the state-of-art OF 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. In the future work, the recommendation is to perform more simulations with dfferent parameters and to provide a research for modifying the OF so that it would provide higher percentage of gain. Also the proposed algorithm for the OF is expected to be implemented in real sensor hardware. In realistic environment, external interference from objects, human body, and other wireless devices using ISM frequency band is expected, so this could be a subject to further challenges.

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