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A proposed routing metric based on the mobility for the RPL protocol

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Abstract- **To offer quality of service (QoS) in wireless sensor network (WSN) where nodes are mobile, routing protocols must be able to adapt to the continuous modification of the topology and to the frequent breakage of radio links. RPL is a protocol that uses routing metrics to manage the mobility of nodes. It is adapted to the limitations of sensors in terms of energy, storage and computational power. However, the metrics that uses RPL do not guarantee in mobile wireless sensor network (MWSN) criteria of performance, such as energy consumption, delivery data with success, response time, etc. In the context of managing the mobility of nodes in this network for the data collection by a mobile sink, we have defined a new routing metric based on the mobility which will be assessed by Report to routing metrics defined in ContikiOS.**

Key words- **RPL, mobile WSN, routing metric, data collection, ContikiOS.**

I. INTRODUCTION

A MWSN is a network with a large number of mobile sensors [1]. The sensors are devices equipped with features of advanced detection (monitor the temperature, the pressure, the acoustics, etc.). They are limited in energy, memory and computational power. They are autonomous, able to communicate between them and transmit data to one or more sinks. This network is usually used to collect data on its environment.

To respond to the limitations of the sensors, standards have been specially designed to guarantee him the QoS while respecting these energy requirements. Our application uses the standards IEEE 802.15.4 [2] and 6LoWPAN (IPv6 Low Power Wireless Personal Area Networks) [3]. The first defines the physical layer and the MAC layer (Media Access Layer), it is designed for WSN. The second is based on this standard. It has allowed the routing of IPv6 packets for the participation of objects limited in energy to the Internet of Objects. In MWSN using these two standards, we can find the protocols ContikiMAC [4] and RPL (RPL: IPv6 routing protocol for Low Power and lossy networks) [5].

ContikiMAC is a MAC protocol that uses the technique of duty-cycle. When sensors use this technique, they have active period and sleep period. The RPL protocol is a routing protocol that allows building, in a MWSN, a DODAG (Destination Oriented Directed Acyclic Graph). In this graph, a sensor assigns a rank corresponding to its location. This rank is the sum of the rank of the parent and the cost of the routing metric. In this article, the metric that we proposed is the result of a calculation that takes into account the parameters which characterize the displacement of a sensor in a MWSN. We named this metric, ARMN (Assigning a Rank to a Mobile Node).

Various applications require the mobility in WSN such as the monitoring of animals, the monitoring using robots, stalking a target, etc. The mobility of nodes has for consequence the frequent breakdown of radio links, and can increase the response time, the loss of packets, etc. In view of these facts, a comparative study of the impact of routing metrics on MWSN is required.

This article is structured as follows. Section 2 introduces MWSN. Section 3 explains the operation of the Protocols ContikiMAC and RPL. Section 4 presents the objective functions. Section 5 presents simulation scenarios and analyzes the results obtained. Section 6 provides a conclusion with prospects.

II. MOBILE WIRELESS SENSOR NETWORK

In MWSN [6], the nodes are embedded in mobile objects (soldier, car, animal, etc.). These mobile nodes are autonomous and communicate between them through radio links.

The advantages of MWSN:

- ➔ Mobility enables to minimize the traffic on some nodes.
- ➔ Minimize the hop-count in a road between a source node and a destination node.
- ➔ The mobile nodes can replace nodes in failures.
- ➔ The mobile nodes can move from an area which is subject to attacks of malicious nodes.
- ➔ A mobile node can connect nodes that are not in the same radio coverage.

The disadvantages of MWSN:

- ➔ The nodes can move fast, slow, randomly or in control. Thus, a node can enter and exit of the MWSN at any time.
- ➔ The dynamic topology is defined by nodes that frequently change position. Thus, a frequent change of roads between nodes.
- ➔ The Frequent breakdown of links between tnodes has for consequence the non-reliability of the established paths between nodes in terms of data delivery, response time, difficulty in locating the nodes that change position, etc.

We can conclude of the advantages and disadvantages of MWSN that it is necessary to have a good organization between nodes to successfully manage the mobility, this depends on the application. Indeed, the benefits show that if the mobile nodes are controlled (movement of a robot, a soldier, etc.), this is beneficial, but the disadvantages show that if the nodes move in a random manner (movement of animals, cars, etc.), this can degrade or improve the performance of the network.

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III. The operation of the main protocols of mobility management in MWSN

A. The operation of the ContikiMAC protocol

The ContikiMAC protocol is a protocol that uses the technique of asynchronous duty-cycle, which is to say that there is no synchronization between the active period and the sleep period. Its operation is that the sensor repeats the transmission of a packet until to the receipt of a acknowledge message or during any its active period.

B. The operation of the RPL protocol

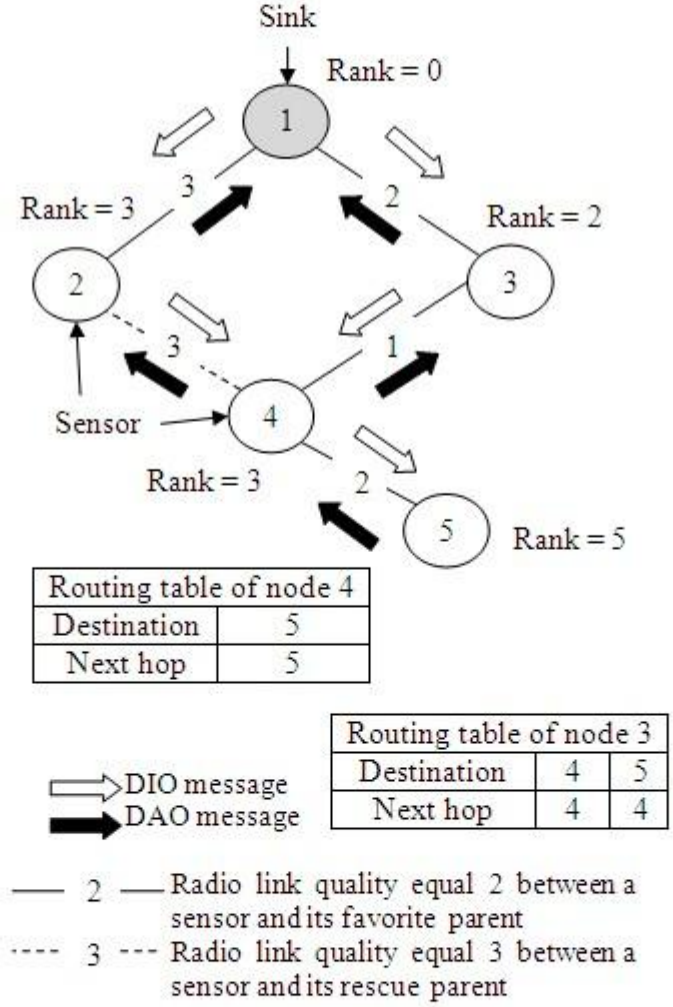

Fig. 1 The operation of the RPL protocol in storing mode with the radio link quality as routing metric

As figure 1 shows, the RPL protocol built in WSN, a DODAG with as destination the sink. The construction of this graph is done through four ICMPv6 messages (Internet Control Message Protocol Version 6) which are DIO (DODAG Information Object), DIS (DODAG solicitation information), DAO (Destination Advertisement Object), DAO_ACK (Destination Advertisement Object Acknowledgment).

To build a DODAG according to a routing metric (energy, hop-count, quality radio link, etc.). The Sink periodically broadcasts a message DIO to the sensors in its radio range. This message contains information such as the rank of the sender and the objective function to use. A sensor which receives a message DIO, calculates its rank by summing the rank of its parent to the cost of the metric. Subsequently, the sensor sends this message to its neighbors. The message DIO can be requested by a DIS message. The sensor adds to its list of parents, the nodes with which it has had the smallest ranks. The preferred parent is the one with which he has had the smallest rank. After this, the sensor informs its parents of its choices by DAO messages. A message DAO may be acquitted by a DAO_ACK message. In figure 1, the routing metric is the quality radio link, the sensors attribute of small costs to the best radio links.

To maintain the roads in the DODAG, the RPL protocol uses the Trickle algorithm which consists that the sensors double the period of sending DIO messages in the case of the receipt of a DIO message not indicating a change in the topology. In the contrary case, the sensors will reset this period to its smallest value.

In our application for the construction of roads between nodes in the DODAG, RPL works in storing mode. In this mode, each sensor sent to its parent, its descendants by DAO messages. In view of this fact, each parent is saved in its routing table, his descendants and the next hop to routing packets. The sink and the leaf nodes do not manage routing table, they transmit their data to the intermediate nodes for routing them to their destinations (see figure 1).

IV. The objective functions

A. Objective Function Zero

The objective function OF0 (Objective Function zero) is based on quality link metric and constraints [6]. In a WSN using this function, each sensor calculates its rank according to the following equation:

$$R(N) = R(P) + Increment \; ;$$
with
$$Increment = (Rf * Sp + Sr) * MinHopRankIncrease \; ;$$

Such as :

- R(N) : The rank of the sensor.
- R(P) : The rank of the parent of the sensor.
- Sp : step_of_rank : Typically, a constant that corresponds to the quality of the radio link. It has a value between 1 and 9.
- Sr : stretch_of_rank : A constant which increases the value of Sp to allow the selection of potential secour parents.
- Rf : A factor used to increase the value of Sp.
- MinHopRankIncrease : The minimum value to increment a rank.

• The advantages of the function OF0:

➔ In static WSN, if the function OF0 is the addition of the rank of the parent to a constant, then the DODAG is the construction of shortest paths to the sink.

• The disadvantages of the function OF0:

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- ➔ In a MWSN, the function OF0 does not allow the construction of shortest paths to the sink.
- ➔ It does not guarantee the reliability of the packets transmission.

B. Minimum Rank with Hysteresis Objective Function

The ETX (Expected Transmission Count) metric allows a sensor to calculate the estimated average number of transmissions of a packet to destination on radio link [6]. In WSN using this function, each sensor calculates ETX as follows:

$$ETX_L = \frac{1}{d_f x d_r};$$

Such as:

- ETX_L: The estimated average number of transmissions for the delivery of a packet to destination on radio link L.
- d_f : The probability that a packet is received by the destination.
- d_r : The probability that an acknowledge packet is sent by the destination.

The objective function MRHOF (Minimum rank with Hysteresis Objective Function) is based on ETX metric such as:

$$R(N) = R(P) + ETX_L;$$

- The advantages of the function MRHOF:
- ➔ The sensors choose radio links offering reliability.
- The disadvantages of the function MRHOF:
- ➔ In WSN using function MRHOF, the sensors choose radio links offering the reliability. However, a sensor may have of the sole choice a radio link which does not guarantee this reliability. This fact will make a path to the sink not reliable.

C. Assigning a Rank to a Mobile Node Objective Function

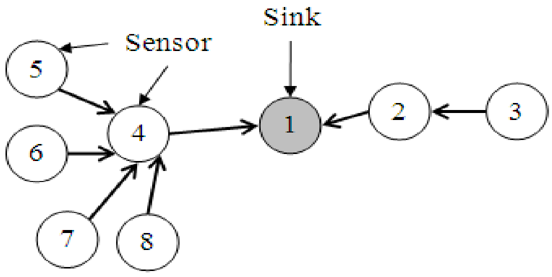

Fig. 2 The main problems in a MWSN using the RPL protocol

As figure 2 shows, the main frequent problems that consume much energy in a MWSN using the RPL protocol:

- A longest paths to the sink.
- A large traffic due to the role of preferred Parent of several sensors.
- The continuous modification of the mobile sensor of its routing table.

Since we study MWSN using RPL, the objective function ARMNOF (Assigning a Rank to a Mobile Node Objective Function) minimize these problems. Indeed, this function is based on the ARMN metric that is the result of a calculation that takes into account the mobility of node. It is the sum of two parameters determined by DIO messages. In MWSN using function ARMNOF, each sensor calculates its rank according to the following equation:

$$R(N) = R(P) + ARMN;$$
with
$$ARMN = Increment\ 1 + Increment\ 2;$$

Such as:

- Increment 1: Nature of the parent of the sensor (see table 1).
- Increment 2: Number of received DIO messages (see table 1).

The values of the two increments are defined in table 1:

TABLEAU I

THE PARAMETERS OF THE OBJECTIVE FUNCTION ARMNOF

Parameter		Value
Increment 1: Nature of the parent of the sensor	Sink	V1
	Sensor	V2
	Without parent	V3
Increment 2: Number of received DIO messages	Between N1 and (N2-1)	V4
	Between N2 and N3	V5

We notified in the objective function ARMNOF, the rules and notes on the table 1:

- ➔ A sink always keeps its rank.
- ➔ The order of the values of the integers V1, V2, V3, V4, V5 is important. Indeed, the value of each parameter of our objective function ARMNOF, defines its priority. Thus, V1 < V2 < V4 < V5 < V3;
- ➔ The order of the values of the integers N1, N2, N3 is important, such as N1 < N2 < N3. These values define the number of received DIO messages for that the sensor continues to increase its rank. Thus, this sensor will manage a minimal traffic.
- ➔ A counter counts the number of received DIO messages. When this number exceeds N3, the counter starts again the account from N1. This constraint is made for that traffic is reasonable on a mobile sensor.

- The advantages of the function ARMNOF:
- ➔ When the sink moves, these neighbor sensors solicit other sensors to choose them as parents.
- ➔ In MWSN, the sensors come in and out of the radio range of the mobile node. Thus, this node will receive several DIO messages, which means that it is possible that it will receive several DAO messages, thus, the possibility to be the parent of several sensors which some will go out of its radio range. These facts have for consequence, a frequent calculation of rank and modification of the routing table. The ARMNOF

ISSN 2356-5608

function allows a sensor either to increase its rank for managed a minimal traffic, either to have a rank due to its position in MWSN.

➔ The choice of the values of parameters of ARMNOF, depend on the frequency of emitting DIO messages, the number of nodes, the radio range of nodes, the mobility of nodes, the speed of nodes, etc. Perform tests on software (Contiki-OS, NS-2, TinyOS…) to confirm the performances of this function on a MWSN [6]. Adaptation to various MWSN.

• The disadvantages of function ARMNOF:

➔ The performances of MWSN depend on the frequency of emitting DIO messages, the number of nodes, the radio range of nodes, the mobility of nodes, the speed of nodes, etc. If one of these parameters changes then the performances of MWSN can be changed (adding nodes, increase the speed of nodes, etc.).

V. Simulation and Analysis

A. *The scenarios of simulation*

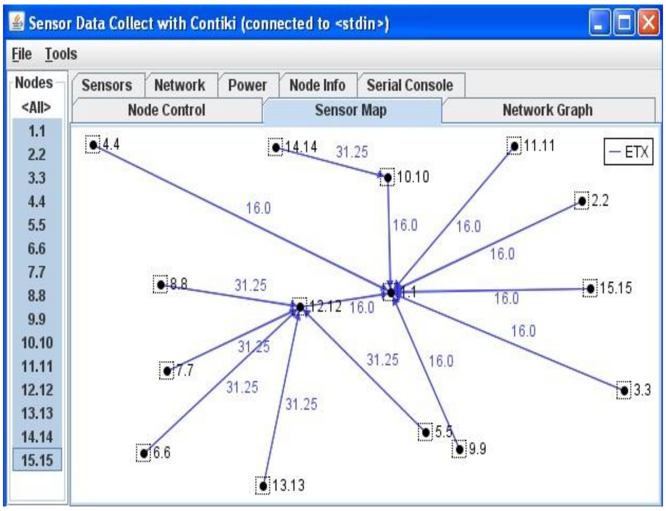

Fig. 3 Data routing in DODAG in the course of MWSN simulation

ContikiOS [7, 8] is an operating system designed specifically for the MWSN. It provides the Cooja simulator (Contiki OS Java Simulator) which allows to simulate MWSN described in Table 2.

We used this simulator for the evaluation of scenarios that assess the impact of routing metrics in MWSN. In this simulation, our application corresponds to the applications for research or environmental monitoring. The data are transmitted by objects (human, robot, car…) to a mobile sink (see figure 3).

TABLEAU II

THE PARAMETERS OF THE MOBILITY MODEL RWP

Parameter	Value
Destination	A position with coordinates (x, y). The values of these coordinates are between 0 and 150 meters
Speed (meters per second)	A value between 1 and 4
The pause time (Seconds)	A value between 2 and 10

Random Waypoint (RWP) is a model of random mobility of nodes [9]. In this model, a node chooses to move in a random speed to a random destination with coordinates (x, y). It takes a random pause time when it arrived to destination. Then, it restarts this movement. This model is often used for the assessment of the performances of routing protocols. It is for this reason that we will use it in our application (see table 2).

TABLEAU III

THE PARAMETERS OF MWSN SIMULATION

Parameter	Value
ContikiOS	Contiki-2.7
Transport protocol	UDP
Routing protocol	RPL protocol in storing mode
Protocol of the adaptation layer	6LoWPAN
MAC protocol	CSMA
Duty-cycle	ContikiMAC
Standard of the physical layer and the MAC layer	IEEE 802.15.4
Topology	DODAG
The nodes	One sink and14 sensors
Radio range of each node	80 meters
Mobility model	RWP
Simulation delay	6 minutes
The interval for emitting data	20 seconds
The minimum interval for emitting the DIO message	4.096 seconds
The maximum interval for emitting the DIO message	1048.576 seconds

To show the impact of objective functions in MWSN, we simulated a network described according to the input parameters of the table 3. The parameters of the mobility model RWP are described in table 2. In this model, the nodes will move in a random manner. In each of the simulation scenarios, this displacement of the nodes will be the same. Indeed, the purpose of this article is to determine the impact of routing metrics on a same mobility of nodes in a MWSN.

TABLEAU IV

THE VALUES OF THE PARAMETERS OF THE OBJECTIVE FUNCTION ARMNOF

	Value	
Parameter	ARMNOF (1)	ARMNOF (2)
V1	1000	1000
V2	2000	2000

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Vol.22 pp.28-34

V3	5000	5000
V4	3000	3000
V5	4000	4000
N1	0	0
N2	25	25
N3	50	40
Rank of sink	256	256

In our application, we assessed function ARMNOF according to the number of received DIO messages for that the sensor continues to increase its rank (see Table 4). Thus, we have:

- Fonction ARMNOF (1) : It is the function ARMNOF which uses the values of the parmeteres described in table 4. In this function, the sensor continues to increase its rank until the reception of 26 DIO messages.
- Fonction ARMNOF (1) : It is the function ARMNOF which uses the values of the parmeteres described in table 4. In this function, the sensor continues to increase its rank until the reception of 16 DIO messages.

B. *Simulation results*

In the course of the simulation, we have obtained results of the following metrics:

- ➢ The energy consumption by the sensor.
- ➢ The duty-cycle that is the cycle where the sensor goes between the sleep mode and the active mode. When the sensor is in the active mode, it has a period of listening and a period of transmission.

We note that the sink is not taken into account, given that we considered it unlimited in energy and always being in active mode (100% duty-cycle). From the results obtained, we have traced the curves in the figures 5, 6 and 7:

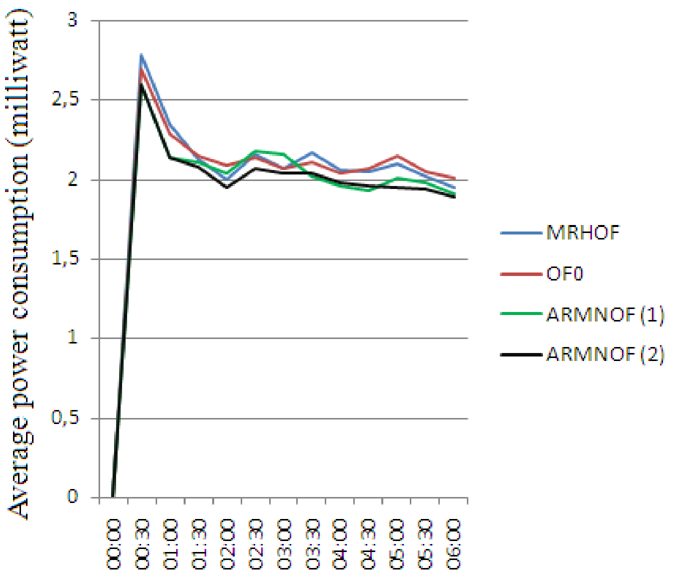

Fig. 5 The average energy consumption of the sensors in each objective function used in MWSN

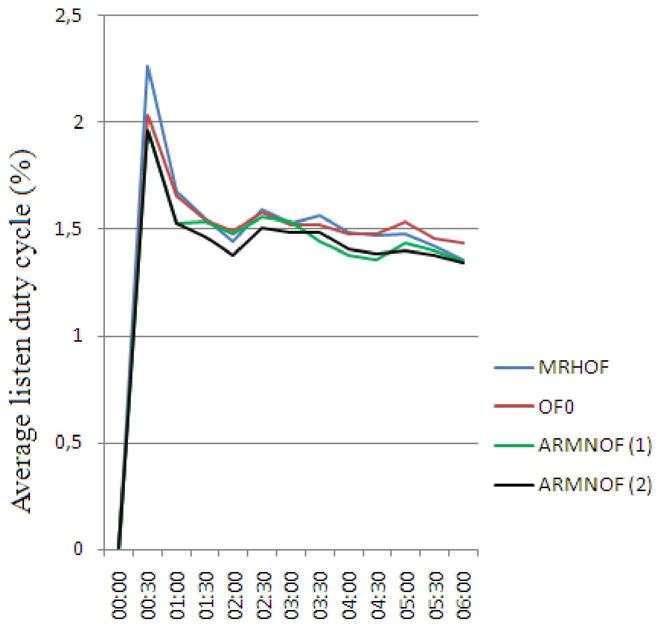

Fig. 6 The average listen duty-cycle of the sensors in each objective function used in MWSN

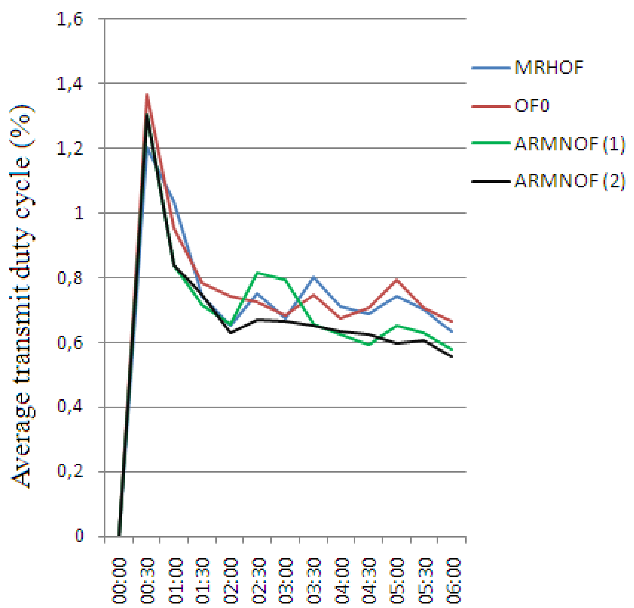

Fig. 7 The average transmit duty-cycle of the sensors in each objective function used in MWSN

The figures 5, 6 and 7 represent in each objective function used in MWSN, the variation through time of the average energy consumption and the active periods of the duty-cycle. What we note :

- The performances of MWSN are random in each studied objective function. Thus ,we compare these functions in a determinate period of time (6 minutes).
- During the simulation, we noted that for each objective function a different topology of the DODAG is obtained. In addition, the frequency of change the sensor of its preferred parent depends on the objective function and the mobility.
- In the first minute, we note in the curves of the three figures a significant increase of the energy consumption and the

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active period of duty-cycle. The reason is the connection of the nodes to MWSN.

- The variations of the curves in these three figures are almost similar. The explanation is that a high energy consumption of few sensors implies major periods of listening and transmission, which implies a large traffic of packets.
- In Figure 5, there are periods, when MWSN uses the function MRHOF, it consumes more energy than when it uses the functions OF0 and ARMNOF (1). Other periods, the contrary is true. The explanation is that the equation for the calculation of the average energy consumed of sensors depends on energy consumption of each sensor. Thus, if some sensors have a high consumption of energy then this average increase. Generally, a sensor consumes much energy when he manages a large traffic (see Figure 3). The objective function ARMNOF takes into consideration the traffic. This explains that in most of the time, when MWSN using ARMNOF, il has obtained better results than when it using MRHOF and OF0.
- During the simulation, the best performances are obtained when MWSN uses ARMNOF (2). When MWSN using ARMNOF (2), it has obtained better results than when it uses ARMNOF (1). Thus, we note in ARMNOF, the importance of the number of received DIO messages for that the sensor continues to increase its rank. The choice of this number depends on the frequency of emitting DIO messages, the number of nodes, the radio range of nodes, the mobility of nodes, the speed of nodes, etc.

TABLEAU V

AVERAGE UDP PACKETS IN EACH OBJECTIVE FUNCTION USED IN MWSN

	UDP packet	
Objective function	**Average received data packets**	**Average loss data packets**
MRHOF	10,786	5,214
OF0	9,786	4,643
ARMNOF (1)	10,929	4,857
ARMNOF (2)	10,5	4,857

At the end of the simulation, we note in table 5 which shows the average UDP packets in each objective function used in MWSN:

- In MWSN using function MRHOF, the sensors choose radio links offering the reliability. However, a sensor may has of the sole choice a radio link which does not guarantee this reliability. This fact will make a path to the sink not reliable. And, this explains the number of loss data packets.
- A MWSN using the function OF0 does not guarantee the reliability of data transmission. This explains the number of received data packets.
- A MWSN using the function ARMNOF takes into consideration the traffic. Thus, the traffic on a sensor must not be large to avoid collisions, and not small for not having a exchange of few data. This explains the obtained results.

TABLEAU VI

AVERAGE ICMPV6 PACKETS IN EACH OBJECTIVE FUNCTION USED IN MWSN:

	ICMPv6 packet		
Objective function	**Average DIO packets**	**Average DAO packets**	**Average DIS packets**
MRHOF	112,533	74,785	8
OF0	84,6	39,5	8
ARMNOF (1)	107,6	49,071	8
ARMNOF (2)	104,666	37	8

At the end of the simulation, we note in tables 6 which shows the average ICMPv6 packets in each objective function used in MWSN:

- According to the Trickle algorithm, more the number of packets DIO is large, more the change of preferred parent has been frequent. Thus, the DODAG built in MWSN using the function OF0 is the one where there has been little change in topology. This fact is reasonable given that the rank of the sensor is equal to the increment of the rank of his parent by a constant.
- In MWSN using function MRHOF, the fact that the number of DAO messages is great, is explained by the large choice of parents.
- We note that the number of DIS packets is the same for MWSN whatever the objective function used. The reason is that the displacement of nodes has not led to the output of a sensor of the coverage area of the network.

VI. CONCLUSION AND PROSPECTS

The study of the impact of routing metrics on MWSN using the RPL protocol, shows that in function of the metric used in the objective function several topologies can be obtained. We note as well that the mobility and the objective function are responsible for the modifications of the roads in a DODAG. Thus, these roads may reduce or increase the performances of the network. Our ARMNOF function takes into account the mobility and the traffic, it is for these reasons that during the simulation, in most of the time, when MWSN using this function has obtained better results than when it using MRHOF and OF0.

Our goal in the result of this work, is to improve the function ARMNOF in order to obtain better results in terms of energy consumption, packet transmission, overhead, duty-cycle, etc.

The end of this article proposes a search of roads taking into consideration the QoS in MWSN.

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